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ESTABLISHING CERTIFICATION/DESIGN CRITERIA FOR ADVANCED SUPERSONIC AIRCRAFT UTILIZING ACCEPTANCE, INTERFERENCE, AND ANNOYANCE RESPONSE TO SIMULATED SONIC BOOMS BY PERSONS IN THEIR HOMES

J. E. Mabry, et al

MAN-Acoustics and Noise, Incorporated

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7. Author(s)
J.E. MABRY, P.B. ONCLEY

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9. Performing Organization Name and Address
MAN-Acoustics and Noise, Inc.
2105 North 45th Street
Seattle, Washington 98103

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16. Abstract

There were two main objectives which were:

Establishing a threshold of acceptability for commercial aircraft sonic booms,

and Investigating and developing the technology to provide a totally realistic simulation approach that can be applied to any community noise problem.

To meet these objectives, seven Community Noise Simulation Systems were designed and fabricated, and simulated sonic booms were introduced, via these systems, into the homes of twelve subject families. Acceptance, interference, and annoyance response data were obtained from the twelve families. Three boom levels and two frequency schedules (average of two or one per hour from 0700 to 2200 hours) were studied.

It was concluded that for establishing a design/certification sonic boom threshold of acceptability for advanced supersonic transports, a level of 87 dB (using S.S. Stevens' Mark VI) should be considered for indoor living with not more than fifteen daily boom exposures (no nighttime booms). It was also concluded that the realistic simulation approach developed utilizing Community Noise Simulation Systems is technically feasible and has high utility. It can be used to establish standards involving traffic noise, noise from airports, construction noise, and effects of industrial noise on surrounding communities.

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PREFACE

MAN-Acoustics and Noise, Inc. is, by any definition, a small company. Thusly, the development of Community Noise Simulation Systems and the associated technology for investigating response to sonic booms from persons in their homes, required that various numbers of our staff function in many capacities. Our first thought was to give the main areas of work and to then list each person who contributed to that main area. This approach would have resulted in several persons being listed a number of times. Consequently, the contributors are listed alphabetically. We want to generously thank all of them. Those who contributed significantly to this program are:

J. M. Bocek

T. G. Dorrance

T. L. Hughes

D. B. Shields

R. A. Shields

B. M. Sullivan

Sections 3. and 4. dealing with equipment and physical acoustics considerations were written by Dr. P. B. Oncley, Senior Research Scientist, while the remainder of the report was completed by Dr. J. E. Mabry. We also want to thank Thomas Higgins of FAA Systems Research and Development Service for his technical guidance and particularly for his interest in testing the Community Noise Simulation Systems approach as a methodology for obtaining noise criteria data. All work in compiling this report was completed by R. A. Shields whom we thank for an outstanding effort.

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1. INTRODUCTION

A major deterrent to the implementation of commercial supersonic flight is that aircraft operating at speeds above threshold mach number create sonic booms heard on the ground. The loudness of these sonic booms is a function of the wave form of the boom (particularly the rise time and overpressure) but the wave form of the boom is very much a function of aircraft design. Thusly, as a means of establishing design criteria for commercial supersonic aircraft, information is required relative to sonic boom levels that would be acceptable by the public. Since existing supersonic aircraft, both military and commercial, were not designed to minimize boom effects, what is required is a totally realistic simulation approach which provides a range of boom levels that communities could find acceptable. The basic aim of the experimental program is to provide the required totally realistic simulation approach. Two specific objectives are to be achieved. They are:

1.1. Establishing a threshold of acceptability for commercial aircraft sonic booms.

Providing data relative to this threshold, in respect to both level and number of booms, will not only provide design criteria but will also lead to certification standards that can be applied to commercial supersonic aircraft.

1.2. Investigating and developing the technology to provide a totally realistic simulation approach that can be applied to any community noise problem.

To achieve this second objective, an innovative approach was conceived. This approach is based on the premise that valid threshold results are obtained by introducing measured sounds into real-life situations and obtaining persons' response to these sounds as they are carrying out their daily living activities.

2. EXPERIMENT DESCRIPTION

2.1 General Considerations

Establishing a threshold of acceptability for commercial aircraft sonic boom noise which has high validity requires exposing persons to boom noises during their usual or daily modes of living. One of the most pervasive daily activities for most persons includes residential living or being at home. Consequently, the general plan involved exposing families to simulated sonic booms in their homes. Completing an experiment based on such a plan requires choices relative to independent measures such as numbers, levels, and orders for presenting the various sonic boom conditions; the dependent measures for estimating a threshold of acceptability; and the selection and characteristics of the subjects who will be completing the experiment. In addition, there is a requirement to develop the signal presentation equipments which permits realistic simulations of the boom signals. A description of the independent measures, and of the subjects is given in this section while acoustical and equipment considerations are provided in the following section.

2.2 Independent Measures

The major concerns in this area are the perceived level or loudness at which to present the boom signals, the number of signals to present, time of presentation, number of hours per day to which families are exposed to the signals, order of presentation for the various experimental conditions, and duration of a particular experimental condition.

2.2.1. Boom Levels It is clear from previous work, both from a theoretical and experimental point of view, that perceived level or loudness is very much a function of both rise time and overpressure. On the basis of this previous work performed in laboratory settings (Ref. 2-1, 2-2) and in conjunction with a pilot study listening experience based on the part of six workers who were working on this study, three levels were chosen with the expectation that they would elicit clearly, possibly, and not acceptable responses from the subject families. The three levels sought were:

•Not Acceptable	81.0 dBA	*92.0 dB (PLH)
•Possibly Acceptable	76.5 dBA	*87.5 dB (PLH)
•Clearly Acceptable	72.0 dBA	*83.0 dB (PLH)

*See Ref. 2-1 & 2-2

Our aim was to introduce signals at these approximate levels and obtain estimates of overpressures and rise times, plus other measures of human response to noise on the basis of calibrated recordings in the subjects' homes. The levels were established on the basis of dBA so they could be checked via an impact sound level meter weighting network. The values in the last column for the three boom conditions are based on the mean incremental difference between dBA and estimates for Stevens' Mark VI and PNdB using an equation from Ref. 2-1 and 2-2. The mean difference is approximately 11 dB and is based on the measured data of Table 6-2 of this report. Details for the measurement program are provided in, Section 4. "MEASUREMENT OF SIMULATED SONIC BOOMS".

2.2.2. Number of Signals to Present The selection of number of signals to present was arbitrary but we did want to make certain that we had exposed the families to the maximum number of booms that they could experience from commercial supersonic aircraft through the year 2000. Consequently, it was decided that each of three main conditions would include thirty (30) booms presented during the waking hours of 7:00 AM to 10:00 PM for a total of fifteen hours and with an average rate of two booms per hour.

2.2.3. Presentation of Experiment Conditions An approach has been established for estimating three levels at which the indoor type boom will be presented as has the number of sonic booms that are to be presented for three main conditions. The next step is to summarize the total experimental situation. For this first study, each family was to take part in the experiment over a six-weeks period involving six conditions, each condition lasting for one week. The six conditions are:

K A control condition which involved installation of the equipment and keeping in touch with the participants so that they would be used to the data collection procedures.

A The high level boom condition (dBA is 81.0) with 30 booms presented over a 15-hour period (7:00 AM to 10:00 PM).

B The middle level boom condition (dBA is 76.5) presented 30 times per day.

C The low level boom (72.0 dBA) presented 30 times/day.

D The middle level boom presented 15 times per day.

E The low level boom presented 15 times per day.

Table 2-1 summarizes the experiment presentation arrangements.

TABLE 2-1. Study design.

		NO. BOOMS	THIRTY BOOMS PER DAY			FIFTEEN BOOMS PER DAY	
	WKS	1	2	3	4	5	6
CONDITION SEQUENCE	1	K	A	B	C	D	E
	2	K	A	C	B	E	D
	3	K	B	A	C	D	E
	4	K	B	C	A	E	D
	5	K	C	A	B	D	E
	6	K	C	B	A	E	D

For weeks "2", "3", and "4" a particular family would be exposed to high, middle, or low level booms in accordance with one of the six condition sequences. Since twelve families participated in the study, two families were exposed to each of the six condition sequences. The aim was to utilize all permutations of the three boom levels so as to permit averaging out of order effects. Conditions D and E (15 booms per day at middle and low levels) were not included in the experiment until some results from conditions A, B, and C (30 booms per day at high, middle, and low levels) had been scrutinized. Thusly, conditions D and E were balanced by presenting middle level booms to one-half of the families during the fifth week while the remaining families were exposed to fifteen low level booms; the levels for each family were reversed for the sixth and last week of the experiment.

2.3. Dependent Measures

Establishing a threshold relative to either the sensation or perception of a measure of energy (sound, light, heat, vibration) requires categorizing of responses as opposed to equal-interval scaling of human response to energy which utilizes approaches such as magnitude estimation or successive intervals calculations (see Ref.2-3). Establishing an auditory threshold at a particular frequency, such as at 1000 Hz, is a straightforward example of category scaling; no attempt is made to scale response as the task is to respond, "Yes, I sense the stimulus", or "No, I do not sense the

stimulus". Stevens' Mark VI and Mark VII are examples of equal interval scaling in psychoacoustics; an increase or decrease of approximately 6 to 10 dB, depending on the characteristic of the signal, either doubles or halves the loudness or perceived level of a sound. Since the main objective is to determine the threshold of acceptability for sonic boom levels, response measures using category scaling (no equal-interval scaling) are emphasized. However, the problem is much more complicated than obtaining a threshold in the classical sense due to the fact that the sounds are clearly audible and that persons bring different personality and attitudinal characteristics into their perceptions. Thusly, response data was obtained emphasizing category scaling but from a number of points of view.

Two somewhat similar schedules were used to obtain participants' response to the various boom conditions, one on a daily basis and the other on a weekly basis at the termination of a particular condition. The daily schedule was used with the "main" participant or the adult who was at home for the greater amount of time. The daily schedule is given in Figure 2-A.

The "main" participant's reactions were obtained by telephone each evening between 9:30 and 10:30 PM. Prior to the start of the experiment, all adults participating were provided copies of the schedule and trained in its use.

The intent of section "A" of the SCHEDULE is readily apparent. For the most part, the aim is to determine if the booms interfered with certain activities, caused annoyance or disturbance. The first nine items of "A" have been used extensively in social survey studies involving annoyance to aircraft noise (Ref. 2-4). Item "B" is aimed at scaling the total eff[illegible] of a daily boom exposure using magnitude estimation. We ex[illegible]ted that this would be a difficult task so each "main" participant was trained using broad band noise prior to the start of the experiment. Section "C" asks the main participant to evaluate their children's response to the booms while "D" is a rating of annoyance on a five-point category scale. For item "E", if they were, at most, moderately annoyed, we were interested in the time period at which annoyance was present. The intent of section "F" was to determine if the subjects found other sounds in their homes as annoying or disturbing as the booms.

The Weekly Noise Schedule (Fig. 2-B) was administered to both adults at the end of each boom condition. The first eleven items are identical to those of section "A" of the Daily Noise Schedule, with

FIGURE 2-A. Daily noise schedule.

A. Hello. This is _____________ .

Did any of the sounds . . .

YES	NO	1.	Startle you?
YES	NO	2.	Keep you from going to sleep?
YES	NO	3.	Wake you up?
YES	NO	4.	Interfere with listening to TV, radio, records, or tapes?
YES	NO	5.	Make the TV picture flicker?
YES	NO	6.	Make the house vibrate or shake?
YES	NO	7.	Interfere with conversation?
YES	NO	8.	Interfere with a telephone conversation? (If no, Did any noises occur while using the phone? YES NO)
YES	NO	9.	Disturb your rest or relaxation?
YES	NO	10.	Interfere with or disturb any other activity? If yes, specify one only:________________
YES	NO	11.	Bother, annoy, or disturb you in any other way? If yes, specify one only:________________

B. How would you rate the loudness of the sounds you experienced today relative to those you experienced during the first day of the program. Remember that the first day of sounds is assigned the number "100" and you are to assign a loudness number proportional to the number "100". ______________

C. In respect to your child (children), was there any indication that the sounds . . . . .

YES	NO	1.	Startled him (her) (them)?
YES	NO	2.	Kept from going to sleep?
YES	NO	3.	Awakened him (her) (them)?
YES	NO	4.	Interfered with or disturbed any other activity? If yes, note two activities:

a.________________ b.__________________

FIGURE 2-A (continued). Daily noise schedule

D. Now, I would like for you to rate the sounds on a 5-point scale as to how much they annoyed or disturbed you.

How much did the sounds annoy you --- almost intolerable, very much, moderately very little, or not at all?

_____a. Almost intolerable
_____b. Very much
_____c. Moderately
_____d. Very little
_____e. Not at all
_____f. Don't know

E. If a,b, or c to D --- When, during the day, did they tend to bother or annoy you?

_____a. Morning (0700 - 1200)
_____b. Afternoon (1200 - 1700)
_____c. Evening (1700 - 2200)

F. YES NO 1. Were there other sounds which you heard in your home today that bothered or annoyed you as much as the sounds we played? (If yes, record up to three noise sources.)

YES NO 2. Any sounds in your home which bothered or annoyed you more than the sounds we played? (If yes, record up to three sound sources.)

FIGURE 2-B. Weekly noise schedule.

Hello, Mr. ________________. First I want to ask you if the sounds caused annoyance or disturbed some of the things you might have been doing. If so, then I'll ask you to give me a rating on a 5-point scale as to how much they disturbed you.

Did any of the sounds . . .

YES NO 1. Startle you? If "yes", how disturbing was the experience of being startled?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 2. Keep you from going to sleep? If "yes", how disturbing was the difficulty in going to sleep?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 3. Wake you up? If "yes", how disturbing was the experience of being awakened?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 4. Interfere with listening to TV, radio, records, or tapes? If "yes", how disturbing was the interference?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 5. Make the TV picture flicker? If "yes", how disturbing was the flickering?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 6. Make the house vibrate or shake? If "yes", how disturbing was the vibrating and shaking?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

FIGURE 2-B (continued). Weekly noise schedule.

YES NO 7. Interfere with conversation? If "yes", how disturbing was the interference?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 8. Interfere with a telephone conversation? If "yes", how disturbing was the interference?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 9. Disturb your rest or relaxation? If "yes", how disturbing was the interruption?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 10. Interfere with or disturb any other activity? If "yes", how disturbing was the interference?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

YES NO 11. Bother, annoy, or disturb you in any other way? If "yes", how disturbing was the annoyance?

___a. Almost intolerable
___b. Very much
___c. Moderately
___d. Very little
___e. Not at all
___f. (Don't know)

How many of the sounds do you estimate you heard during the week? ______

WORKING ADULT ONLY:

YES NO 1. Are there other sounds occurring in your home which bother or annoy you as much as the ones we played? If yes, record up to three noise sources.

YES NO 2. Are there any sounds which occur in your home that bothered or annoyed you more than the ones we played? If yes, record up to three noise sources.

FIGURE 2-B (continued). Weekly noise schedule.

BOTH ADULTS:

If the sounds you were exposed to this week were to continue indefinitely in your neighborhood . . .

YES	NO	Would they be acceptable to you?
YES	NO	Could you learn to live with them?
YES	NO	Would you move to another neighborhood?

the exception that if a participant responded "yes" to any of the eleven items, they were then asked to rate the "amount" on a five-point category scale. Also, the adult (usually the husband) who tended to be at home less than the main participant was asked if he found that other sounds in the home were equally or more annoying than the booms. Finally both adults were asked the three key questions concerning the possibility that the sounds for that week would continue on indefinitely in their neighborhood. If nearly all persons were to respond "yes", "yes", "no" to these last three questions, we would conclude that the level and number of booms presented for that experiment condition was a conservative estimate of the threshold of acceptability. The Weekly Noise Schedule is given in Figure 2-B.

2.4. Subjects

The twelve subject families were recruited via the following advertisement in a Seattle evening newspaper. There was an unexpectedly strong response to the advertisement and it was clear that

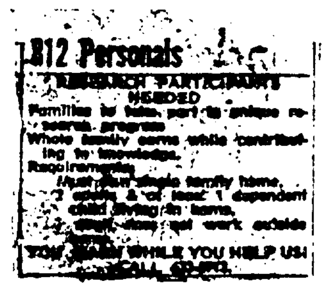

812 Personals

FIGURE 2-C. Advertisement placed in Seattle evening newspaper for recruiting subject families.

we would not be able to work with all the families who were interested in participating. The sequence in hiring subject families is as follows:

- A brief explanation of the program was given at the first telephone contact. Ages of family members, number of years of schooling completed by adults, family income, and home address were obtained.

- The above information was then examined and for those selected both husband and wife were asked to visit our laboratory.

as per orig.

- During this first visit, we demonstrated some of the impulse noises to which they would be exposed. We gave them more information relative to the requirements of the program and agreement was reached as to their participation.

As part of the study, all members of each family were examined audiometrically and a noise oriented social survey was administered to each adult. One of the aims of collecting the social survey data was to make certain that we had selected families that represented a fairly broad socio-economic spectrum. Also, there was interest in whether or not some of their attitudes concerning noise could be qualitatively related to their responses to the simulated sonic boom conditions. Following are summaries of pertinent characteristics describing the subject families. The question or characteristic investigated is given along with tabulation of the subjects' responses.

1. How do you like living in your neighborhood? Do you rate it as an excellent, good, fair, poor, or very poor place to live?

   The wives were more inclined to rate their neighborhood as an excellent place to live than were the husbands; 92 percent of the wives rated their neighborhood as "good" or "excellent" while 82 percent of the husbands rated their neighborhood "good" or "excellent".

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
Excellent	67%	46%
Good	25%	36%
Fair	8%	18%
Poor	---	---
Very Poor	---	---
(Don't Know)	---	---

2. Do you like many things, just a few things, hardly anything, or nothing at all about living around there?

   More than 80 percent of the respondents (both wife and husband) "like many things" about living in their neighborhood.

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
Many Things	84%	82%
A Few Things	8%	18%
Hardly Anything	8%	---
Nothing at All	---	---
(Don't Know)	---	---

3. **What are some of the things you DON'T like about living in your neighborhood?**

This open-ended question was examined for whether-or-not noise was mentioned. Twenty-five percent of the wives spontaneously reported that noise was one of the things they did not like about their neighborhood while 18 percent of the husbands mentioned noise.

4. How noisy or quiet do you think this neighborhood is? Very noisy, somewhat noisy, somewhat quiet, very quiet?

Notice that 50 percent of the wives rate their neighborhood as on the noisy side while only 9 percent of the husbands perceive their neighborhood as being noisy.

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
Very Noisy	17%	9%
Somewhat Noisy	33%	---
Somewhat Quiet	42%	82%
Very Quiet	8%	9%
(Don't Know)	---	---

5. When you're inside your house, does noise in the neighborhood bother or annoy you very much, moderately, very little, or not at all?

Both wives and husbands report very little annoyance from neighborhood noise while in their homes.

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
Very Much	8%	---
Moderately	8%	18%
Very Little	34%	36%
Not at All	50%	46%
(Don't Know)	---	---

6. When you're inside your house, which is the MOST bothersome noise from the neighborhood that you hear?

WIFE		HUSBAND	WIFE		HUSBAND
Barking dogs	1	Lawn mower	Dogs barking	7	Nothing
Hotrodding cars	2	None	Screeching cars	8	Dogs
Motorcycles	3	Kids noise	None	9	Dogs barking
Hot rod car	4	Small airplane	Trucks	10	Trucks
Motorbikes	5	Geese and bantam chickens	Trucks	11	Nothing
Honking car	6	Cars	Boat whistles	12	Nothing

This question almost forces the respondent to give the MOST bothersome noise in the neighborhood. Approximately 67 percent of the wives mentioned noise associated with ground transport (cars, trucks, motorcycles) while only one of the husbands responded in the ground transport category. One-third of the husbands responded "none" or "nothing" while only one of the wives would not name a "MOST bothersome" neighborhood noise.

7. Each adult participant responded to a ten item noise sensitivity test which had been utilized in a number of previous studies **(Ref. 2-5). The ten items are:**

(1) To hear water dripping from a tap.
(2) To hear a neighbor's radio, television, or phonograph playing loudly.
(3) To hear chalk squeaking on a blackboard.
(4) To hear heavy traffic continually pass my house.
(5) To hear dogs barking or cats fighting when I am trying to go to sleep.
(6) To hear a low-flying jet pass overhead.
(7) To hear a pneumatic drill working outside my house.
(8) To hear the prolonged crying of someone else's baby.
(9) To hear the telephone ring for a long time.
(10) To hear interference on the television or radio.

Subjects responded using:
_____ a. Extremely annoying
_____ b. Moderately annoying
_____ c. Slightly annoying
_____ d. Not annoying

The ten items were then scored on the basis of 0, 1, 2, 3 with "0" for Not Annoying and "3" for Extremely Annoying. This means that scores to the test could range from 0 to 30. Results are given in Table 2-2.

TABLE 2-2. Mean and range of scores to noise sensitivity test.

	WIVES	HUSBANDS
MEAN	22.2	18.4
RANGE	13 - 28	13 - 25

Both wives and husbands scored relatively high on this noise sensitivity test with wives reporting greater sensitivity to noise than husbands. For a previous study involving 180 adult subjects (Ref. 2-5) the mean response was 15. 4 and the scores ranged from a low of "2" (very insensitive) to a high of "27" (very sensitive to noise). For a second earlier study involving 40 English subjects, the mean score was 14. 9 (Ref. 2-3). The lowest score for any of the twenty-four persons from this present research program was 13 which is quite close to the average scores for the previous two studies. Clearly, these subjects see themselves as being unusually sensitive to noise.

8. Compared to other people, are you more aware of noise than others, about the same as others, or less aware of noise than other persons?

Wives tend to report that they are more aware of noise compared to others than do husbands.

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
More Aware	33%	18%
Same as Others	42%	55%
Less Aware	25%	27%

9. Some people have said that "pollution is one of the biggest problems of modern times". Would you agree strongly, agree somewhat, disagree somewhat, or disagree strongly with that statement?

The wives clearly agree strongly to a greater extent than do the husbands that "pollution" is a serious problem.

PERCENT RESPONDING TO CATEGORIES

	WIFE	HUSBAND
Agree Strongly	75%	27%
Agree Somewhat	17%	55%
Disagree Somewhat	8%	18%
Disagree Strongly	---	---
(Don't Know)	---	---

10. The preceeding paragraphs provide attitudinal kinds of information from those participating. This section gives objective characteristics relative to socio-economic level, age, family composition and so on. Table 2-3 provides data concerning length of time the family has lived in their neighborhood, whether-or-not they are owning or renting, years of schooling completed by the head of the household, and the number of persons living in the home.

TABLE 2-3. Some characteristics of participating families.

How long lived in neighborhood	Average of 5.2 years	Range of 1 to 18 years
Own or renting	83% own	17% rent
Schooling of head of household	Average of 13.5 years	Range of 10 to 16 years
Number in household	Average of 4.5 persons	Range of 3 to 8 persons

The occupations for the twelve heads of the households were as follows:

Meteorological Technician	Greenskeeper
Service Representative	Writer
Public Relations	Utility Maintenance
Auto Body Repair	Carpenter
Wholesale Florist	Treasurer
Glassblower	Vice Pres., Mgt Serv.

TABLE 2-4. Summary of income for participating families.

YEARLY INCOME	PERCENT INCLUDED
Under $5,000	----
5,000 - 9,999	16.5%
10,000 - 14,999	42.0%
15,000 - 19,999	25.0%
20,000 or more	16.5%

A summary of family income is shown in Table 2-4. The majority of the families were in a middle income range of ten to fifteen thousand dollars per annum while 16.5 percent were under $10,000 with the same number earning more than $20,000 per year.

Table 2-5 provides the final information on family characteristics which is a summary of ages for the head of the households.

TABLE 2-5. Summary of ages for heads of households.

AGE CATEGORIES (Years)	PERCENT IN CATEGORY
20 - 24	8%
25 - 29	25%
30 - 34	8%
35 - 39	34%
40 - 49	--
50 - 59	17%
60 - 69	8%

The distribution of ages for the heads of households fairly well covers the range of ages for adults with the majority falling in the middle to late thirty category. The median age is approximately 37 years of age.

11. Results to some of the attitudinal questions given above are not particularly meaningful unless they are compared to those obtained from a sample of persons that can be considered representative of a larger population. Responses to these same questions were obtained from adult respondents residing in 659 randomly selected households (Ref. 2-6). Table 2-6 gives pertinent results from this previous study and those for the husband and wives of the present study. The Paragraph Number heading the first column of Table 2-6 corresponds to the numbered paragraph of this section in which more detailed results are presented. Under "Item" in Table 2-6, a synopsis of the question is given while the third column gives the "Category" that was selected for comparison. The last three columns provide percents responding to that category so that comparisons can be made.

TABLE 2-6. Comparison of some attitudinal results to those from a larger, previous study (Ref. 2-6).

PARA. NO.	ITEM	CATEGORY	PREVIOUS STUDY	WIFE	HUSBAND
1.	Rate neighborhood?	Excellent	27.9%	67%	46%
2.	How many things like?	Many things	54.1%	84%	82%
3.	Things you don't like?	*(Open-end ques.)	27.6%	25%	18%
4.	How noisy or quiet?	Somewhat quiet	42.4%	42%	82%
8.	Awareness of noise?	More aware	23.8%	33%	18%
9.	Pollution question.	Agree strongly	65.8%	75%	27%

*Percent is for those who mentioned that some noise event was not liked.

Using the results from the previous numbered paragraphs, a profile of the subject families is given.

(a) Both wives and husbands are more likely to rate their neighborhood as "Excellent" than persons interviewed on a randomly selected basis. Also they are inclined to like "many things" concerning their neighborhood to a greater extent than persons in the larger, random sample. Both the wives and husbands like their neighborhoods.

(b) Noise was mentioned as one of the things (open-ended question)

that was not liked by the wives to about the same degree as those from the previous study but husbands were slightly less concerned with neighborhood noise. The wives reported that their neighborhood was "somewhat quiet" to almost the same extent as found in the larger, previous study but the husbands were much more inclined to report that their neighborhood was "somewhat quiet". The wives rate their neighborhood as being, on the average, about as noisy as others rate their neighborhoods, but the husbands see their neighborhood as being very much on the quiet side.

(c) Both wives and husbands are much more sensitive to noise than are persons responding to the identical noise sensitivity test. In respect to "awareness of noise", the wives do report that they are more aware than the larger group (33% to 23.8% respectively) while the husbands are slightly under the comparison group.

(d) The data presented in paragraph 10. shows that a wide range of occupations and incomes were present for the subject families although no unusually "poor" or "rich" families took part in the experiment.

2. REFERENCES

2-1. MABRY, J. E., and PARRY, H. J., "The effect of simulated sonic boom rise time and overpressure on electroencephalographic wave forms and disturbance judgments", FAA-RD-73-115, July 1973.

2-2. HIGGINS, T. H., and SANLORENZO, E. A., "Psychophysical tests of potential design/certification criteria for advanced supersonic aircraft", Report No. FAA-RD-75-10, Feb. 1975.

2-3. MABRY, J. E., and PARRY, H. J., "An evaluation of psychoacoustic procedures for determining human response to aircraft noise", Report No. FAA-RD-72-51, Vol. I and II, October 1973.

2-4. BORSKY, Paul N., "A new field-laboratory methodology for assessing human response to noise", NASA CR-2221, March 1973.

2-5. The Boeing Company, "Study and development of turbofan nacelle modifications to minimize fan-compressor noise radiation - Vol. VII. Subjective evaluation tests", D6-60120-7, Under NASA Contract No. NAS 1-7129, 1970.

2-6. MABRY, J. E., "City of Portland and Multnomah County system noise management program", Contract No. USE-OR-10-00-0003, December 1974.

3. ACOUSTICAL AND EQUIPMENT CONSIDERATIONS

3.1. Wave Form Considerations

The basic wave form of a sonic boom can be described by an "N-wave" which can be expressed in three parameters: (1) rise time to first maximum, (2) peak overpressure, and (3) duration between positive and negative pressure maxima. Although the actual sonic boom may depart from this shape as a result of ground reflections, ground absorption, atmospheric distortions and phase shift, etc., the N-wave is a valid and repeatable form which can be considered the same as the first for purpose of synthesis.

The frequency spectrum of the symmetrical N wave can be closely approximated by the expression:

$$P(\omega) = iADj_1(\pi f D) \times j_0(\pi f R) \qquad (3\text{-}1)$$

where A is the peak overpressure, D is the duration, R is the rise time, and j_1 and j_0 are spherical Bessel functions of the first kind, and first and zeroth order:

$$j_0 = (\sin y)/y\,, \quad \text{and}$$
$$j_1 = [(\sin x)/x^2] - [(\cos x)/x]$$

This derivation and a typical plot for a duration of 350 msec. and a rise time of 5, 10, and 20 msec. are given by Oncley and Dunn (J. Acoust. Soc. Am. 43, 889-890), reprinted as Appendix 1 to this report.

Filtering or differentiation which affects only the spectrum components below 20 Hz does not change the sound of the N-wave, and should not be a factor in its acceptability. (This does not exclude, however, the possibility that infra-sonic frequencies may affect building structures, which may in some cases generate rattles or other audible sounds.) This finding has been experimentally verfied by several investigations including a study at the Boeing Company conducted by J. E. Mabry (now with MAN-Acoustics and Noise, Inc.) and J. W. Little. The report on this study is incorporated in this report as Appendix 2. For the purposes of the present study, the actual filter cut-off point was 40 Hz rather than 20 Hz due to loudspeaker limitations, but there was unanimous agreement on the part of listeners with experience in evaluating actual outdoor sonic booms that a very adequate simulation was attained.

3.2. Equipment Requirements

3.2.1. Reproducing Systems Since the simulated sonic boom was presented to two groups of six households, six signal generation systems, plus a seventh system retained in the laboratory as a control and spare, were required. Each system had four loudspeakers installed in various rooms of the house, except that in one very small cottage only three speakers were required. The equipment installed in each house is shown schematically in Figure 3-A.

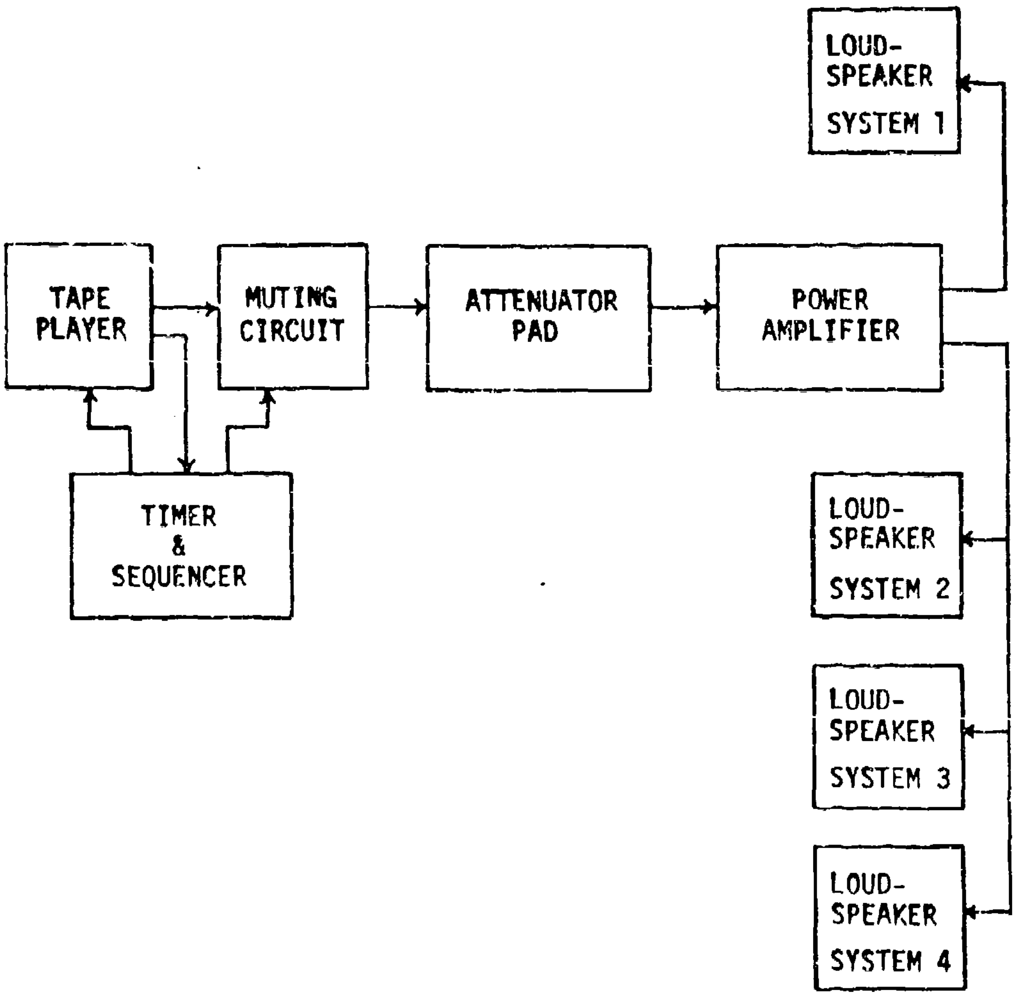


FIGURE 3-A. Block diagram of sonic boom reproduc..g systems.

The tape players employed were modified Sony TC-208 eight-track, two channel stereo tape decks operating at 3-3/4 ips. Sony specifications list a 50 to 10,000 Hz frequency response, 50 dB signal-to-noise ratio, 3% harmonic distortion, and 0.25% wow and flutter. By pre-emphasis in recording the low frequency range was held flat to 40 Hz. Modifications were made to the control system to disable the automatic track switching mechanism and to start the tape on command from the timing mechanism. Only two tracks were used, of which one was the N-wave, modified by pre-emphasis and high-pass filtering as described later, and the other was a pilot tone at approximately 10,000 Hz, beginning 10 msec. before the N-wave, which opened a muting gate in the amplifier input. This gate effectively enlarged the signal-to-noise ratio of the system by eliminating background hum and hiss and starting transients associated with tape start-up which would otherwise have provided the test subjects with a warning cue. Care was also taken to eliminate mechanical noise of the tape start-up by acoustic enclosure of the tape deck wherever needed.

The timing circuit was designed to accept a quasi-random program stored on a re-programmable Read-Only-Memory (ROM) integrated circuit chip. A block diagram of the timing and control circuitry is given in Figure 3-B.

The 24-hour timer, operated off the power mains, serves to disable the system after 10:00 PM and reactivate it each morning at 7:00 AM. All counters are reset to zero each morning except one which denotes the day and advances the ROM address to a new position each morning. Different programs are stored on the ROM for each of eight days, although the system is reset manually each week when the attenuator settings are changed, so the program of the eighth day is not normally used.

A step-down chain reduces the 60 Hz power line frequency to one pulse every four minutes, so the separation between test stimuli is always some multiple of four minutes. The number stored for each signal in the ROM represents the number of four-minute increments until the next impulse. Likewise the counter denotes the number of four-minute increments elapsed since 7:00 AM. The latch circuit holds a zero initially and the binary adder outputs the sum of the latch circuit and the number stored in the ROM at the initial address. If, for instance, the initial ROM number is 4, the adder will present 0 + 4 = 4. At 7:16 the counter becomes equal to 4 and the coincidence circuit sends a pulse to activate the tape drive, and also to reset the latch circuit

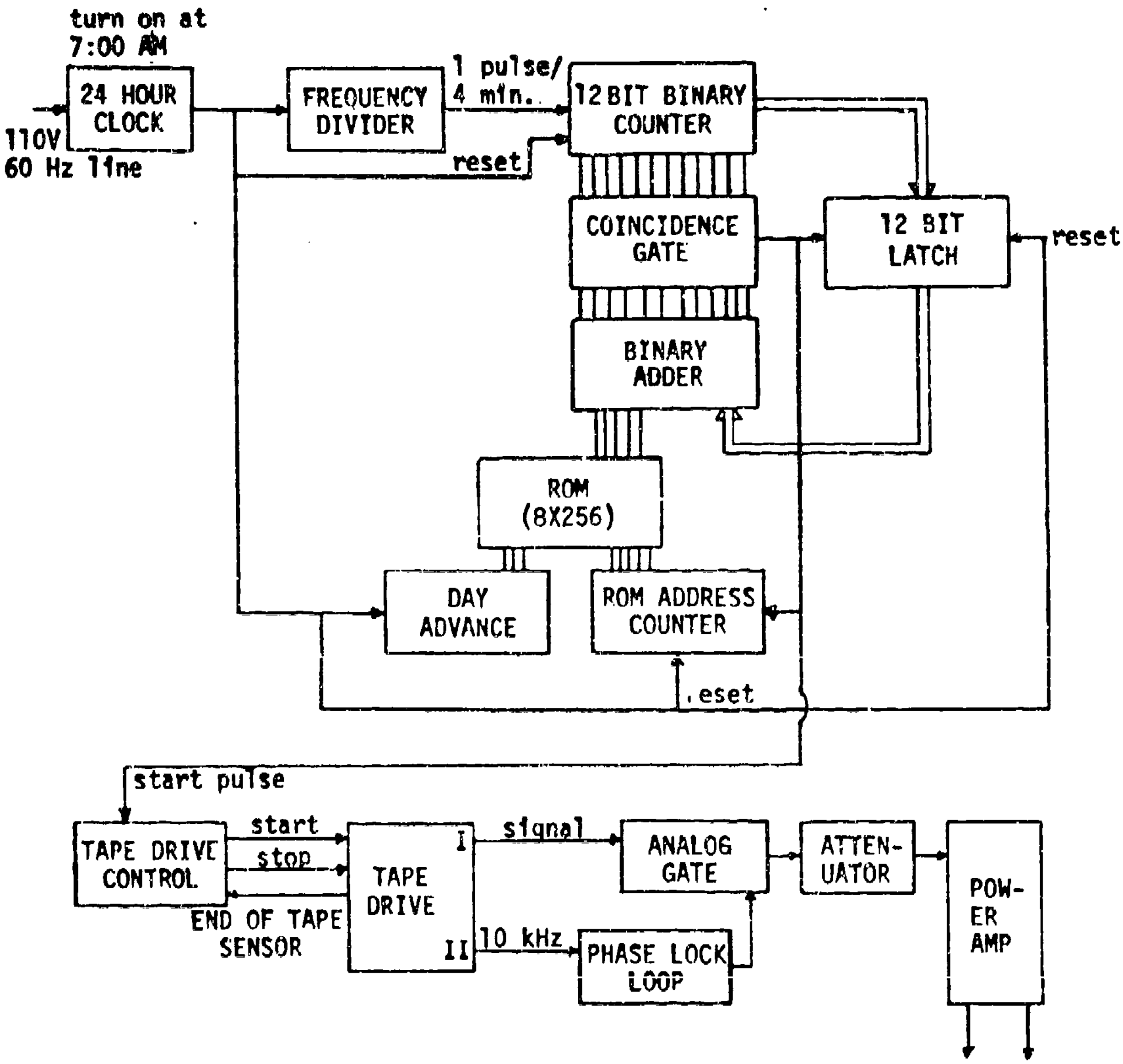


FIGURE 3-B. Timing and control circuitry.

to the current counter value of 4 and to advance the ROM address counter to a second number.

The ROM stores thirty numbers for each day, generating thirty booms. They were determined from a table of random numbers, from 0 to 10, to which 2 has been added so the shortest increment is 8 minutes, and the longest, 48. They were then further tested to discard groups of thirty which totalled more than fifteen or less than fourteen hours. As noted earlier, different programs for eight days were stored on the ROM, and the 24-hour clock advanced the program each day. Programs on successive weeks were identical so the only variable was signal amplitude.

Additional circuitry activated a high speed advance control on the tape drive after the pulse, but since only a single pulse was required and the tape loop was short, the fast forward control was later deleted. (The same system was to be used later for flyover noise tests, so some of the control circuitry was more complicated than needed for sonic boom tests alone.)

The power amplifiers used were McIntosh MC2100 Solid State Stereo Power Amplifiers, rated at 105 watts per channel, with response flat within 0.25 dB from 20 to 20,000 Hz and typical distortion of 0.1%. Less expensive amplifiers could have been used, but the reliability and flexibility of these amplifiers led to their selection. The inputs were parallel, giving separate gain controls and outputs for the primary speaker system and for the three parallel secondary speakers.

The primary speaker system used a room-corner reentrant horn for low frequencies, following the design published by Paul Klipsch (J. Acoust. Soc. Am. 13, 137-144; 17, 254-258). Frequencies from 350 to 5000 Hz are reproduced by a fiberglass exponential horn, and a high efficiency horn tweeter reproduces frequencies from 5 kHz to above 17 kHz. The Klipsch horn takes advantage of the high acoustic impedance of the room corner to operate at high efficiency (approximately 30 - 40%) down to its 40 Hz cut-off frequency. The system easily handles the full 105 watts of the amplifier and is believed to be the best speaker system commercially available for wide-range, high power reproduction. The speaker systems were built by Speakerlab of Seattle as their System K. One of these was installed in the primary living area in each home tested.

The other three speakers were also built by Speakerlab as their System 2. It is a less expensive direct radiator type with 60 watt

power handling ability particularly designed for rock music. The woofer is a 10", cloth roll suspension cone type, with a 28 Hz free air resonance. Three smaller cone speakers reproduce frequencies above the 2500 Hz crossover. Since the low frequencies from the Klipsch horn pervade the entire house, these speakers compensate for the loss of highs to give a realistic boom signature at all points. They were installed in hallways, kitchens, bedrooms, etc., at points selected to give the most even sound distribution possible.

Levels were initially set separately for the primary and secondary systems. Using a General Radio Type I Sound Level Meter, Model 1933, at a distance of 4 feet and on the axis of the midrange tweeter of the Speakerlab K, the gain control, with a zero attenuation pad, was set to 81 dBA, using the "Impulse" meter response. Since the three Speakerlab 2 systems were connected in parallel, the level was measured at one of the speaker positions, also adjusted to 81 dBA at four foot. Levels were then changed to the selected test condition by inserting a 4.5 dB, 9 dB, or zero loss fixed attenuation pad. Experiment conditions (boom level and number) are given in section 2.2.

3.2.2. Signal Generation The N-wave was generated by an electronic circuit, shown schematically in Figure 3-C. The timing chain is made up of type 555 one-shot multi-vibrators, and the time constants of each are adjusted by external resistors and capacitors. The rise time of 25 msec. and duration of 350 msec. were chosen in consultation with the program manager, but any other values can be substituted. The pulses are combined and then integrated, using operational amplifiers and standard circuitry. A gain adjustment must be provided so the total direct current value of the integrated positive and negative values adds up to zero.

The GR 1925 Multifitter serves several functions. First of all, it is used to cut off frequencies below 40 Hz which would not be reproduced by the recording system and which could damage the speakers. Secondly, it serves as an accurate equalizer to compensate for uneven frequency response in the recorder-reproducer system and in the loudspeakers. It includes thirty 1/3-octave band pass filters covering frequencies from 3.15 to 80,000 Hz, with slide type logarithmic attenuators permitting a 50 dB range of attenuation in 1 dB steps in each band.

The compensation curve was developed by recording "pink noise" (equal power per 1/3-octave band) from a General Radio

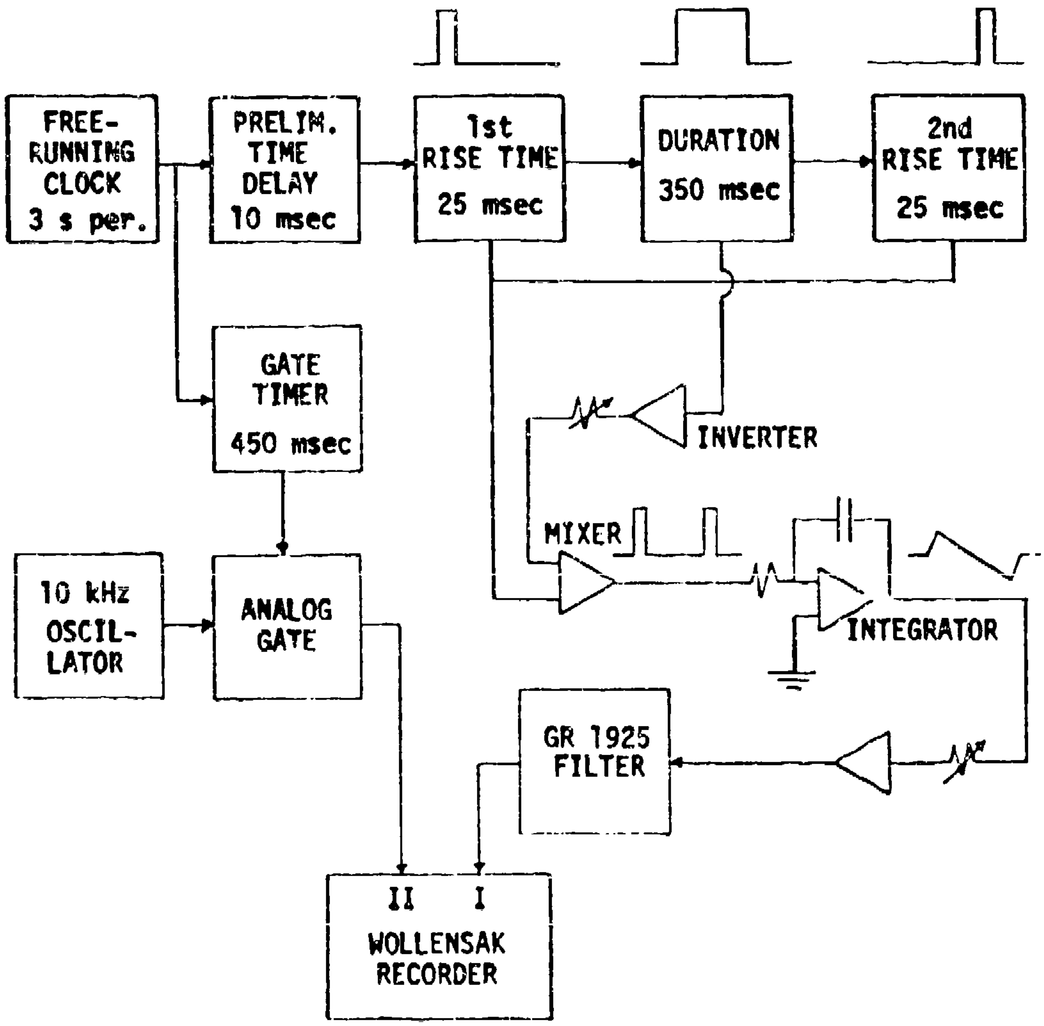


FIGURE 3-C. N-wave recording system.

Model 1582 on the Wollensak recorder used for the N-wave recordings. The tape was replayed on the Sony TC-208 through the McIntosh MC2100 amplifier and the Klipsch horn loudspeaker system, just as the signal would be in the homes. The noise from the loudspeaker was picked up with the GR 1933 Sound Level Meter and was analyzed by the GR 1921 Real Time 1/3-octave band analyzer, using a 32-second integration time. The response of the overall system was thus obtained, and is given in Figure 3-D. (There was some variation between speakers, but the curve is typical and was used for all tapes). The compensation curve, introduced through the GR 1925 Multifilter, is a mirror image of this curve, except for the sharp low frequency cut off and a high frequency roll off to reduce tape hiss. There is very little signal from the N-wave above 1000 Hz in any case. The compensation curve is shown also in Figure 3-D.

Figure 3-E shows the overall system response when compensation was introduced in the initial recording from the pink noise source. Using increased bass compensation, it was possible to obtain the dashed curve, flat within ±2 dB from 30 to 10, 000 Hz at the loudspeaker output. With the N-wave source, however, the speaker excursion at the very low frequencies was excessive, and it proved preferable to cut off as shown by the solid line in Figure 3-E. With this response a higher power could be obtained and the ear's sensitivity is so low at 40 Hz that the reduction in low frequency was not audible. Since the sonic boom spectrum has virtually no energy above 1000 hz, it also proved preferable to reduce the high frequency response somewhat to minimize background noise.

Figure 3-F(a.) shows an oscillogram of a typical N-wave as produced by the circuit of Figure 3-C, not including the GR 1925 Filter and the Recorder. The rise times are each 25 milliseconds, and the duration from peak overpressure to peak underpressure is 350 milliseconds. The oscilloscope time base is 50 milliseconds per division. Filtering drastically changes the wave form as seen in curve (b), which shows the effect of a 30 Hz high-pass filter. This change of shape does not change the audible sound of the signal, however. Figure 3-G(a) gives the 1/3-octave spectrum of the unfiltered N-wave, measured from the electrical signal by the GR 1921 analyzer (dotted stepped curve). The spectrum of the N-wave after 30 Hz high-pass filtering is shown by the stepped solid curve (b). The two are essentially indistinguishable above 40 Hz. The smooth curve is the narrow band transfer of an N-wave with 25 msec. rise times and 350 msec. duration, calculated from

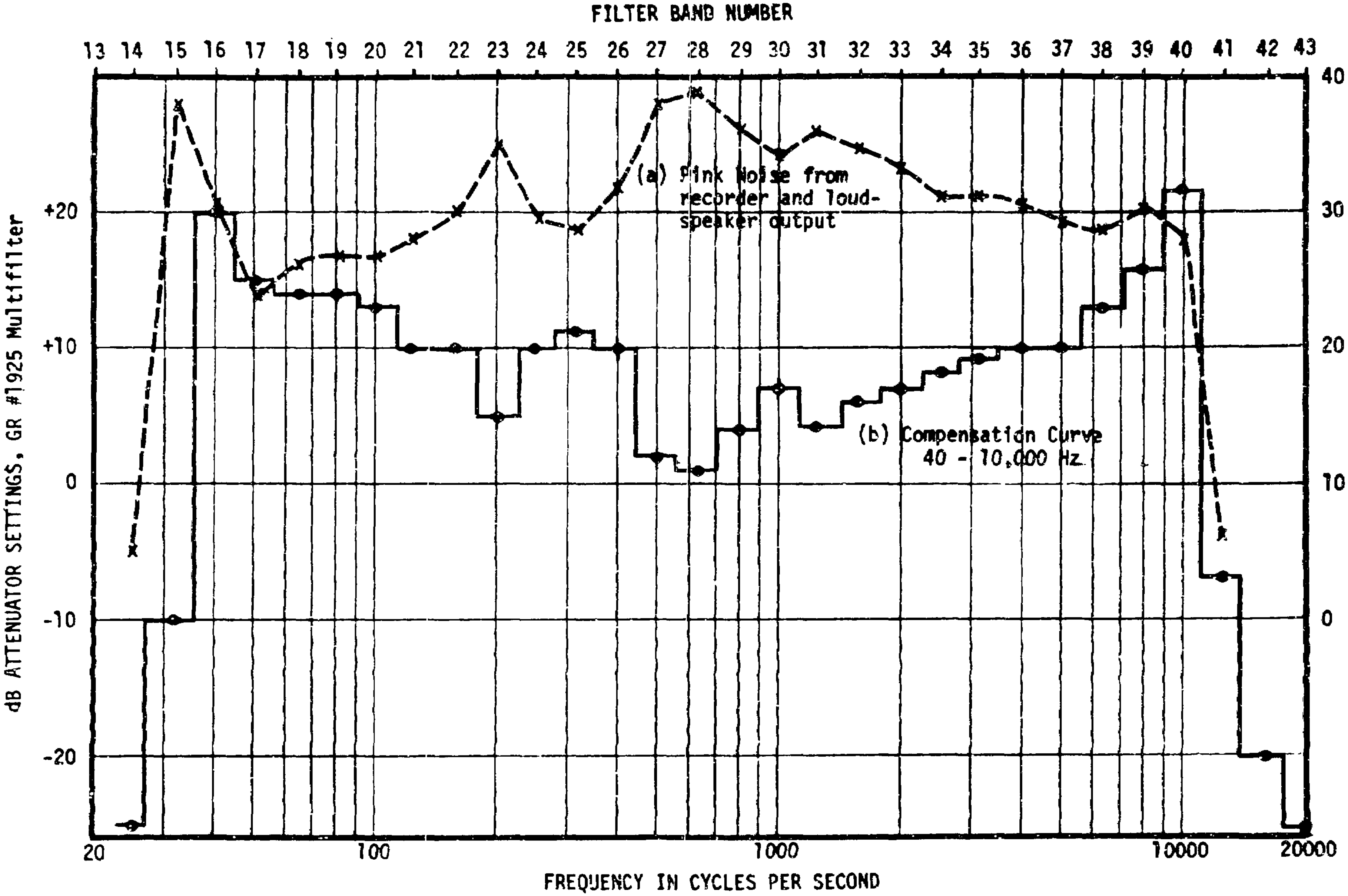


FIGURE 3-D. (a) Pink noise response of Record and Playback System (uncompensated) and (b) Complementary compensation curve.

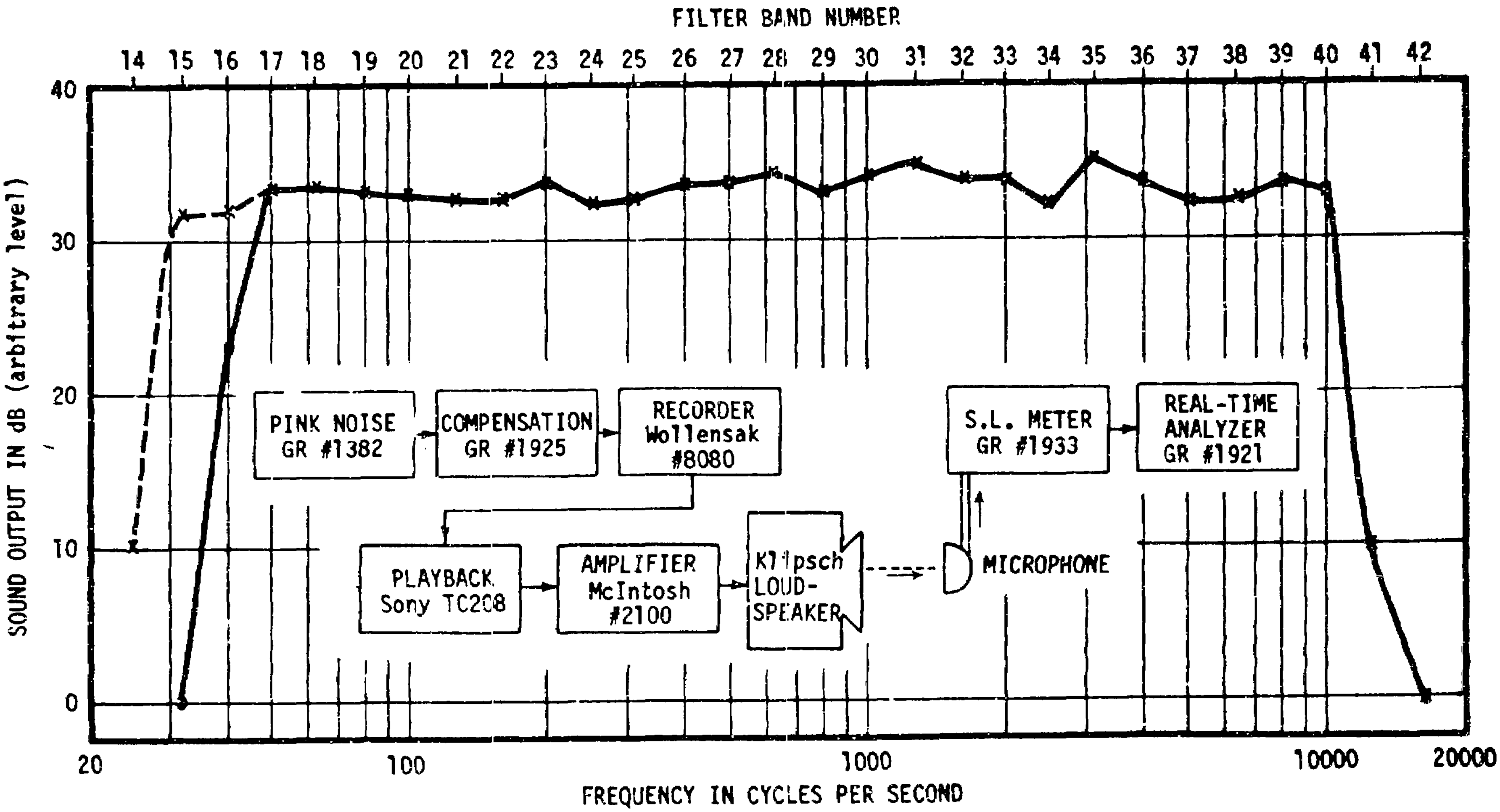
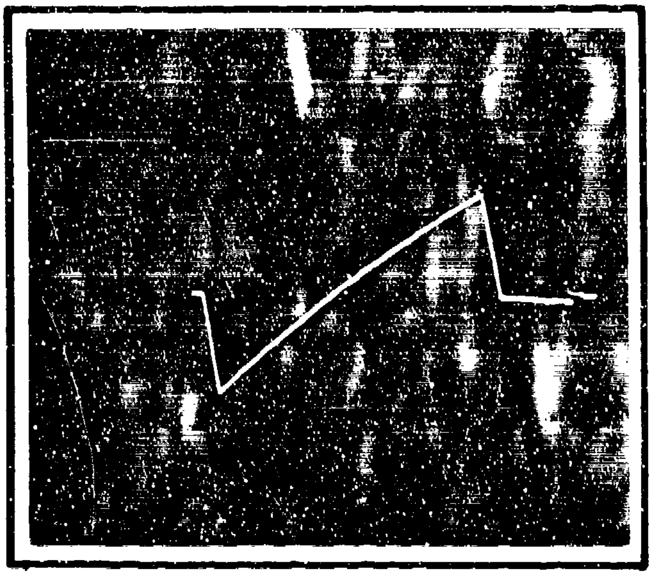
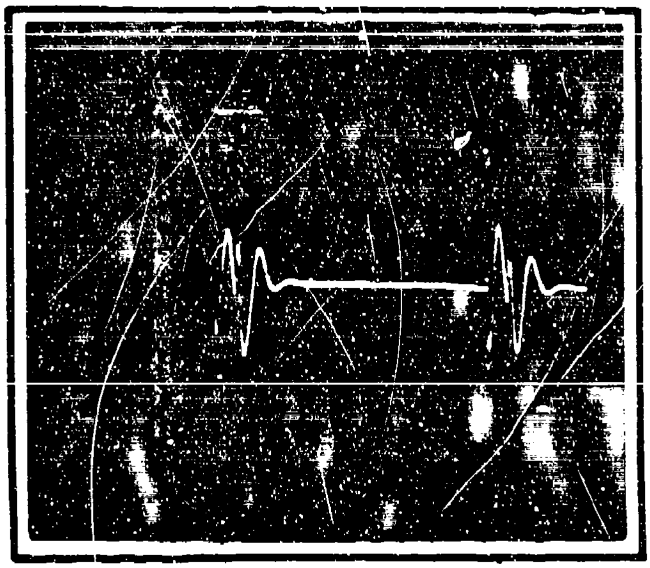


FIGURE 3-E. Overall system response (compensated).



a. Unfiltered.



b. With 30 Hz high pass filter.

FIGURE 3-F. Oscillograms of N-wave,
R = .025 sec., D = .350 sec.

equation (3-1) in paragraph 3.1.2. with the addition of 3 dB/octave. This addition is to make it easier to visualize the similarity between the narrow band spectrum, on a unit energy per cycle basis, and the 1/3-octave spectrum, with unit energy per band, since the band width of the filters increases with frequency. The way in which the 25 msec rise time causes a dip in the 80 Hz response is clearly evident. The 40 Hz dip is not easily detected where the filter cut-off is about 40 Hz, and higher frequency dips are somewhat smeared by the relatively wide 1/3-octave band.

Measured spectra from the acoustic output also show good agreement with the electrical spectra within the audible range. There were minor production variations in the speaker systems, and since the compensation curve was matched to one typical system and was used for all, there is some variation in the measured acoustic spectrum at the various locations.

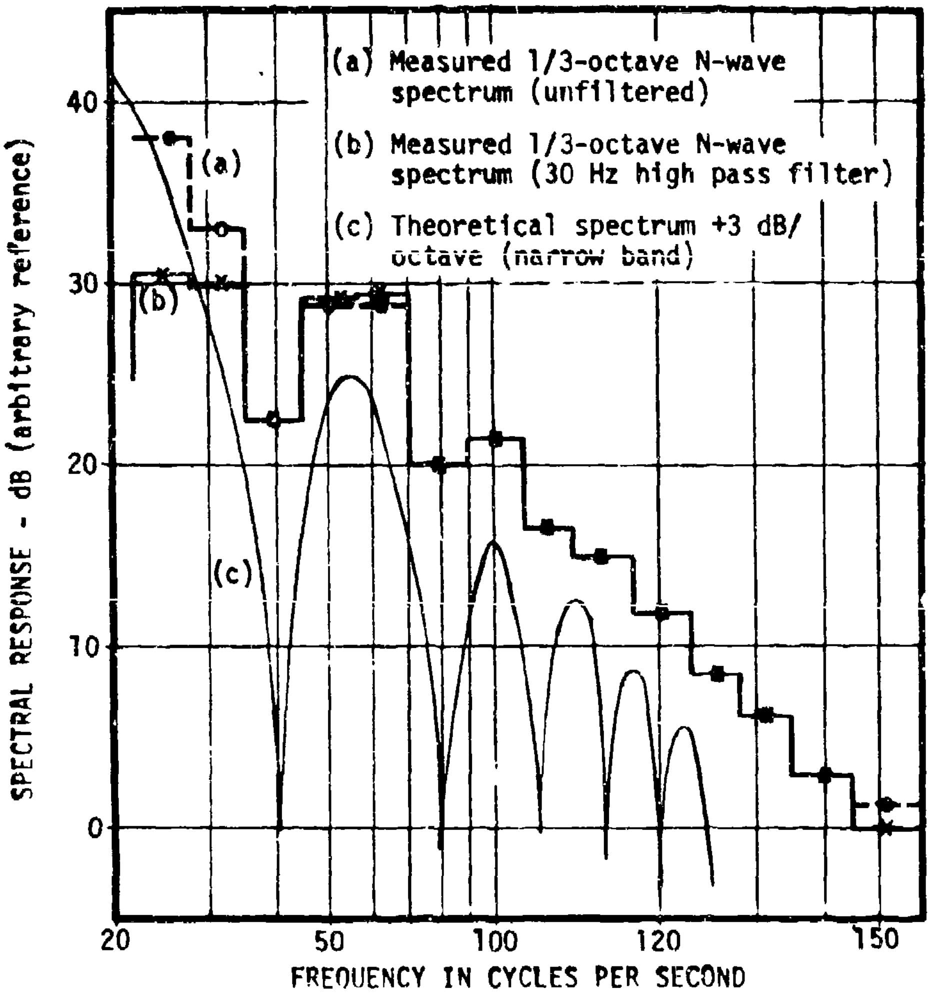


FIGURE 3-G. Measured and theoretical spectra of N-wave, R = .025 sec., D = .350 sec.

4. ANALYSIS OF SIMULATED SONIC BOOMS

Since the shape of the original N-wave has been modified in the recording and playback process, there are complications in interpreting the final results in terms of peak overpressure. It has been shown earlier that the subaudible spectrum components do not contribute to the sound of a sonic boom, and those components have been eliminated in the steps of filtering, pre-equalizing, recording and reproduction. Likewise, the original phase relations have been altered, but this does not change the sound. These changes do radically alter the amplitude-time function, as seen on an oscillograph, so it no longer has the appearance of an N-wave in the time domain, as was shown in Figure 3-F.

In the frequency domain, however, the spectrum above the low-frequency cut-off should remain essentially unchanged by the filtering and recording process. By the analysis in Appendix A it is possible to determine the absolute amplitude of all spectrum components of an N-wave in terms of its peak overpressure (A), duration (D), and rise time (r).

$$P(f) = 4AD\left\{\frac{\sin(\pi fD)}{(\pi fD)^2} - \left[\frac{\cos(\pi fD)}{\pi fD}\right]\left[\frac{\sin(\pi fr)}{\pi fr}\right]\right\} \qquad (4\text{-}1)$$

Figure 4-A is a plot of the frequency spectrum of an N-wave with a duration of 350 milliseconds and a 25 millisecond rise time. It is a composite curve: the position above 20 Hz is an automatic plot of the Fast Fourier transform of a computer-generated N-wave with those parameters. The band width is of the order of about one Hertz, so to get better resolution, the curve below 20 Hz was calculated from equation 4.1 on a PDP-11 computer, and was hand-plotted, giving a calibrated spectrum level with respect to the peak overpressure (A).

Three regimes are recognizable in Figure 4-A.

(1) Below the peak frequency at 1.8 Hz, the curve is asymptotic to a +6 dB/octave straight line. The peak frequency is inversely proportional to the N-wave duration.

(2) Between 1.8 Hz and about 20 Hz, there are a series of maxima and sharp minima generated largely by the

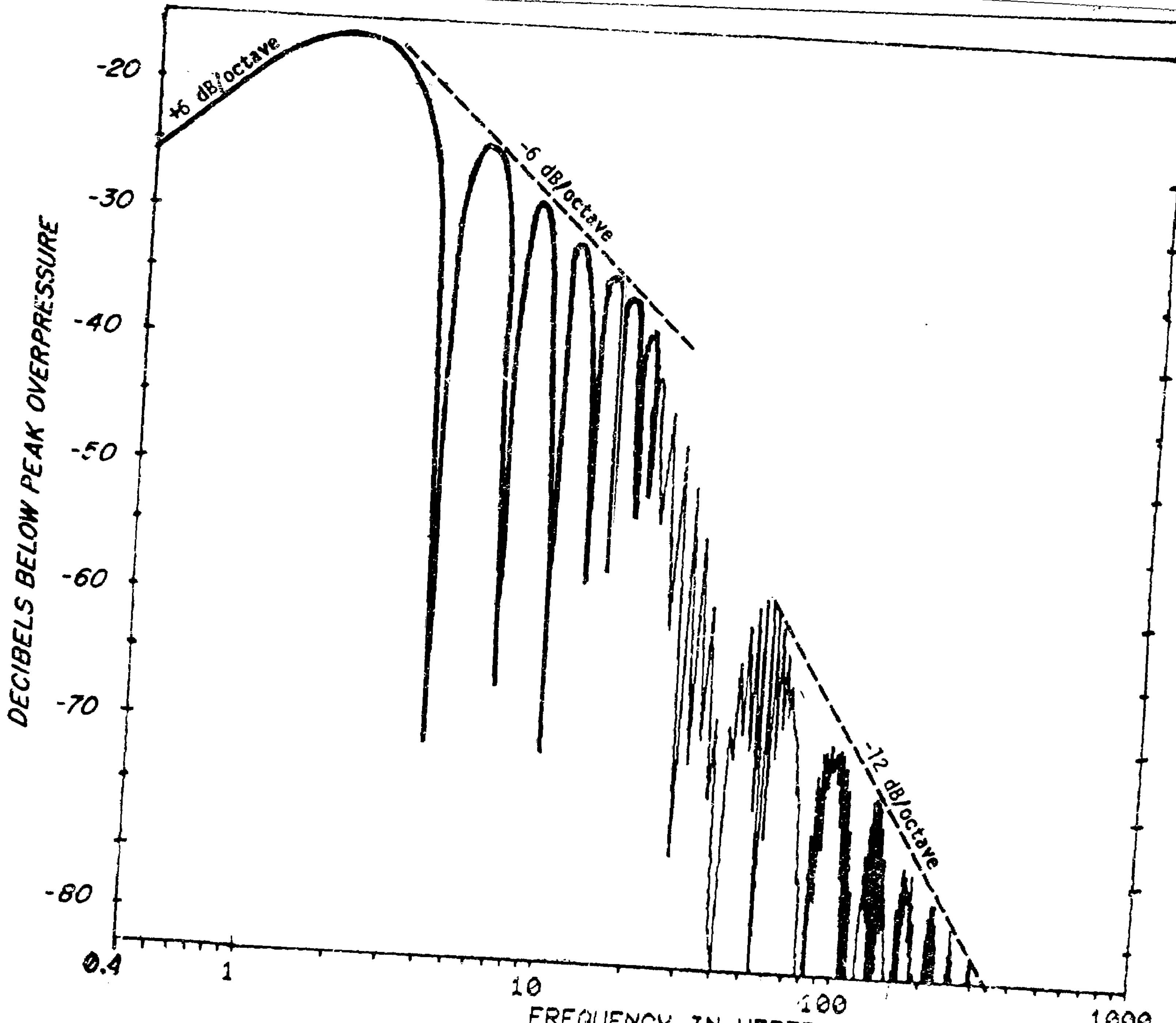


FIGURE 4-A. Calculated Fourier Transform, N-wave with D=.35, R=.025 sec.

cos(πfD)/(πfD) function in equation (4-1), with minima when fD is approximately 3/2, 5/2, 7/2, etc., since the first term gets very small as fD product increases in the squared denominator. The locus of the maxima is asymptotic to a -6 dB/octave slope in this region.

(3) At higher frequencies the rise time function, sin(πfR)/(πfR), becomes significant. For small values of the argument, the sine and the argument are nearly equal, and the ratio is close to unity, but when fR = 1/2, 3/2, 5/2, etc., the function goes to zero, giving a second series of maxima and sharp minima modulated onto the envelope of the cos (πfD)/(πfD) function. Since the maxima of this rise time function also fall off at a -6 dB/octave rate, the maxima of the total curve now fall off at -12 dB/octave above a transition point proportioned to 1/R. In this regime the first term is almost negligible and the expression is basically the product of the two Bessel functions: cos(πfD)/(πfD) and sin(πfR)/(πfR).

Fourier transforms, presented as Figures 4-B to 4-N, were obtained of the boom stimuli as actually recorded in each of the test homes. By comparing the audible spectrum of these transforms with a similar region of the theoretical curve it should be possible to determine the peak overpressures of an N-wave which would have generated the equivalent auditory effect. The transforms were made in another laboratory, and unfortunately there was a misunderstanding in the calibration procedure which has made it impossible to rely on the absolute levels determined by this method.

Instead, the approximate overpressures given in Tables 4-1 through 4-3 have been calculated from the Stevens Mark VI data using the engineering method suggested by Higgins (Ref. 4-1). He has shown that the PNL is closely approximated by a Perceived Level (PLdB) defined by

$$\text{PLdB} = 55 + 20 \log_{10} (\Delta P/\Delta t)$$

where ΔP is the peak overpressure in pounds per square foot and Δt is the rise time in seconds. Measurements in our laboratory as well as elsewhere have confirmed the approximate validity of this expression for the ranges under consideration.

It will be noted that the Fourier transform spectra do not agree

in detail with one another or with Figure 4-A, chiefly because of resonances in the various rooms. The frequencies in which we are most interested, from 30 to 200 Hz, lie in the region where low order resonances can be expected in most living rooms. The homes represented varying economic levels: some were large and some were small; some had heavy draperies and thick carpets while some were relatively bare.

By way of example, the living room of Family 3, Figure 4-D, was nearly square, about 11 x 13, with an alcove in one corner which extended the dimensions on that side to 13 x 14. Fundamental resonances are 40.2 Hz (14'), 43.3 Hz (13'), and 51.1 Hz (11'). These broad resonances overshadow the predicted narrow dip at 40 Hz. The floor to ceiling resonance for an 8' ceiling is about 70 Hz and the second harmonic of the 14' length comes in at 80 Hz. The dip at 62 Hz can be explained from the fact that the microphone at 4 ft from the speaker is 4.54 ft from each wall, and a null point is expected where this distance is a quarter wave. This turns out to be precisely 62.0 Hz.

The home of Family 2 represented in Figure 4-C, was smaller, but was typical of an open design where living, dining, and kitchen areas form an "L", and are only partly separated by room dividers. The speaker was in the corner of the "L", with a 22' distance to the kitchen wall in one direction and the same distance to the living room wall. The living-dining area was 15' wide. The 22' length gave a fundamental resonance at 25.5 Hz which was below the speaker cut-off frequency, but the 15' dimension gives a resonance at 37.5 Hz which gives the first strong peak. The combination of 22' and 15' comes in at 45.4 Hz, and the second harmonic of the 22' distance gives a 51.1 resonance.

It is not profitable to pursue this analysis much further. In the next octave or two there are a great many eigenmodes which modify the spectral structure. If the signal source had been an actual sonic boom from an aircraft, the variation in recorded indoor patterns would have been equally noticeable. The thing which is significant is the general slope of the spectrum maxima above 80 or 100 Hz, and in each case the -12 dB/octave slope is recognizable. Since the components below 60 Hz contribute little to loudness, the frequency at which the -12 dB slope begins is very important. Figure 4-P, for instance, is the Fourier Transform of an N-wave with 10 msec rise time. The -6 dB/octave slope extends to about 40 Hz, with a first

TABLE 4-1. Summary of analysis of simulated sonic boom - MAXIMUM LEVEL (-0 dB attenuation).

FAMILY NO.	dBA	dBD	IBE	PNL	PL6	PL7	OVER-PRESSURE psf
1	84.18	97.09	94.67	101.47	100.00	92.54	4.45
2	77.84	91.95	87.64	93.15	91.74	84.74	1.72
3	81.64	93.76	90.96	96.75	95.57	87.10	2.67
4	76.92	92.01	87.31	92.01	90.56	83.38	1.50
5	83.60	98.06	93.84	98.15	95.88	90.25	2.77
6	84.60	97.87	94.67	100.87	98.86	92.00	3.90
7	82.70	95.30	92.59	97.47	95.85	88.66	2.76
8	81.74	97.35	92.38	98.76	97.50	88.04	3.33
9	79.89	95.59	90.91	96.91	95.97	87.00	2.80
10	80.50	95.31	90.91	97.29	96.20	87.75	2.87
11	81.40	93.40	90.36	96.58	94.38	87.79	2.33
12	81.63	92.37	90.08	97.21	94.98	87.91	2.49
MEAN	81.4	95.0	91.4	97.2	95.6	88.1	2.80

dip at 100 Hz. The -12 dB/octave region beyond 150 Hz is masked above 300 Hz by system noise, but a comparison of Figures 4-P and 4-A shows clearly the higher spectrum level in the range of 40 to 400 Hz produced by the shorter rise time.

The recorded spectra from the speakers in each home were also analyzed by 1/3-octave bands, using the General Radio Model 1921 Real Time Analyzer, and were combined into various ratings as given in Tables 4-1, 4-2, and 4-3. The recordings in each case were of the Klipsch speaker system, at a four-foot distance. Table 4-1 represents the loudest boom (-0 dB) and Table 4-2 and 4-3 represent attenuation pads calculated to give -4.5 and -9dB respectively.

TABLE 4-2. Summary of analysis of simulated sonic boom - INTERMEDIATE LEVEL (-4.5 attenuation).

FAMILY NO.	dBA	dBD	dBE	PNL	PL6	PL7	OVER-PRESSURE psf
1	79.72	92.83	90.46	96.71	95.15	87.54	2.54
2	73.05	87.89	82.87	88.23	86.78	79.51	0.97
3	77.69	89.61	86.96	92.47	91.01	82.76	1.58
4	74.51	88.61	84.61	89.61	87.67	80.61	1.08
5	79.49	93.52	89.46	94.05	91.83	85.73	1.74
6	80.75	94.03	90.82	96.21	94.24	87.22	2.29
7	77.51	89.91	87.22	92.71	90.87	83.48	1.55
8	77.24	92.85	87.88	94.26	93.00	83.54	1.99
9	74.00	89.98	85.10	91.07	89.90	80.76	1.39
10	75.98	90.57	86.28	92.81	91.68	83.23	1.71
11	74.59	87.10	83.97	90.12	88.83	81.00	1.23
12	74.83	86.28	83.83	89.51	87.96	80.32	1.11
MEAN	76.6	90.3	86.6	92.3	90.7	83.0	1.60

The engineering calculation procedures of Tables 4-1, 4-2, and 4-3 are calculated from the 1/3-octave spectra by the standard methods. The last columns in Tables 4-1, 4-2, and 4-3, Peak Overpressure in PSF, were calculated from the PL6 values using the equation of Ref. 4-1. Note that the mean of the dBA values which were calculated from the calibrated tape recordings are very close to those set in the homes on the basis of the impact sound level meter. Values sought were 81.0, 76.5, and 72.0 dBA while mean values obtained were 81.4, 76.6, and 72.4 dBA respectively.

TABLE 4-3. Summary of analysis of simulated sonic boom - LOW LEVEL (-9 dB attenuation).

FAMILY NO.	dBA	dBD	dBE	PNL	PL6	PL7	OVER-PRESSURE psf
1	75.50	88.24	85.90	92.94	91.63	83.36	1.70
2	68.38	83.01	78.04	82.09	82.16	74.73	0.57
3	72.84	84.61	82.05	87.22	85.86	77.62	0.87
4	70.51	84.40	80.57	85.64	84.15	76.28	0.72
5	75.18	89.11	85.01	89.68	87.87	81.18	1.10
6	75.61	88.87	85.68	91.08	89.30	81.84	1.30
7	73.46	85.86	83.21	88.34	86.81	79.07	0.97
8	72.74	88.35	83.38	89.76	88.50	79.04	1.18
9	69.85	85.10	80.49	86.50	85.27	75.90	0.82
10	71.53	86.34	81.94	88.27	87.21	78.39	1.02
11	71.51	83.41	80.39	85.99	84.78	76.87	0.77
12	71.98	82.84	80.47	87.78	86.75	78.39	0.97
MEAN	72.4	85.8	82.3	87.9	86.7	78.6	1.00

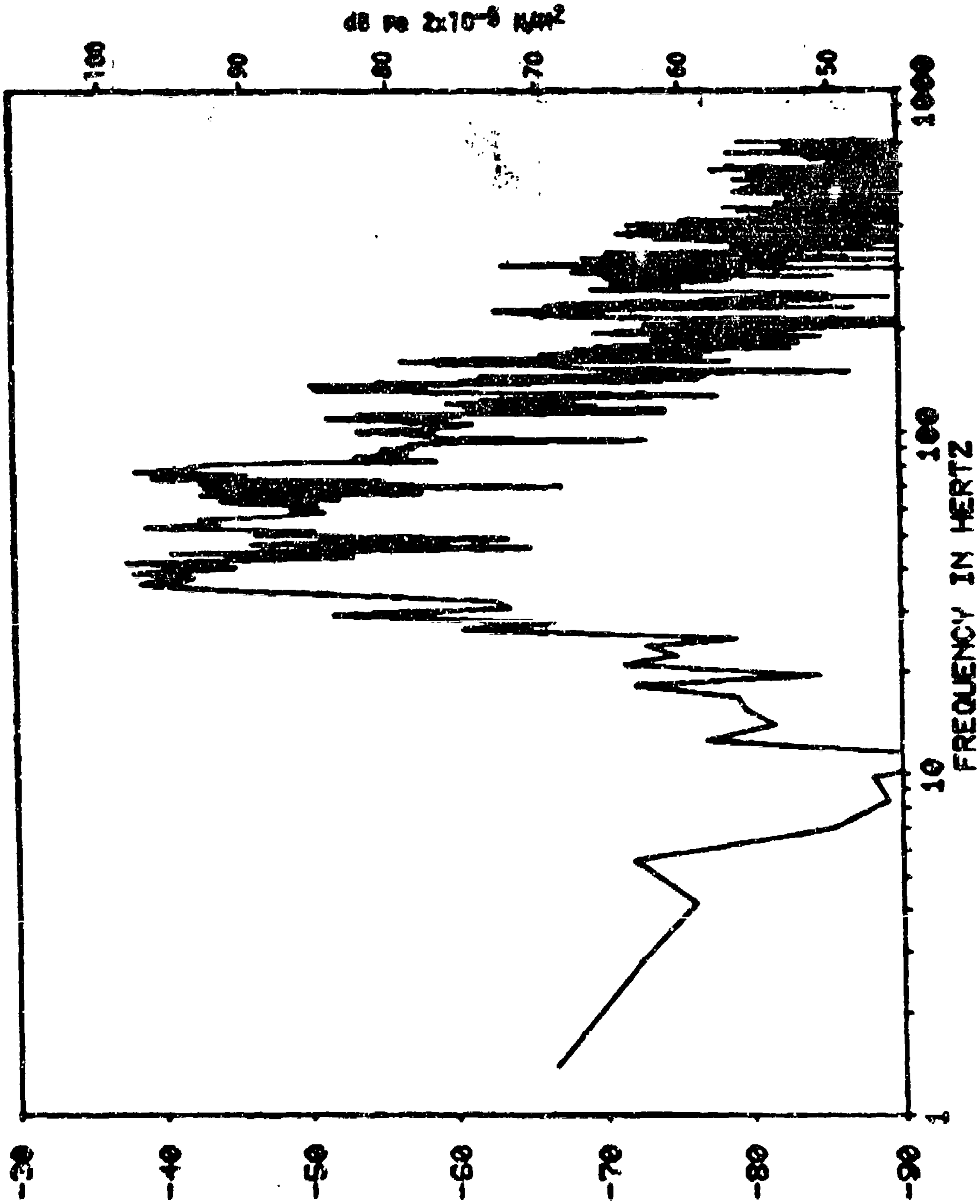


FIGURE 4-8. Fourier Transform - Family 1.

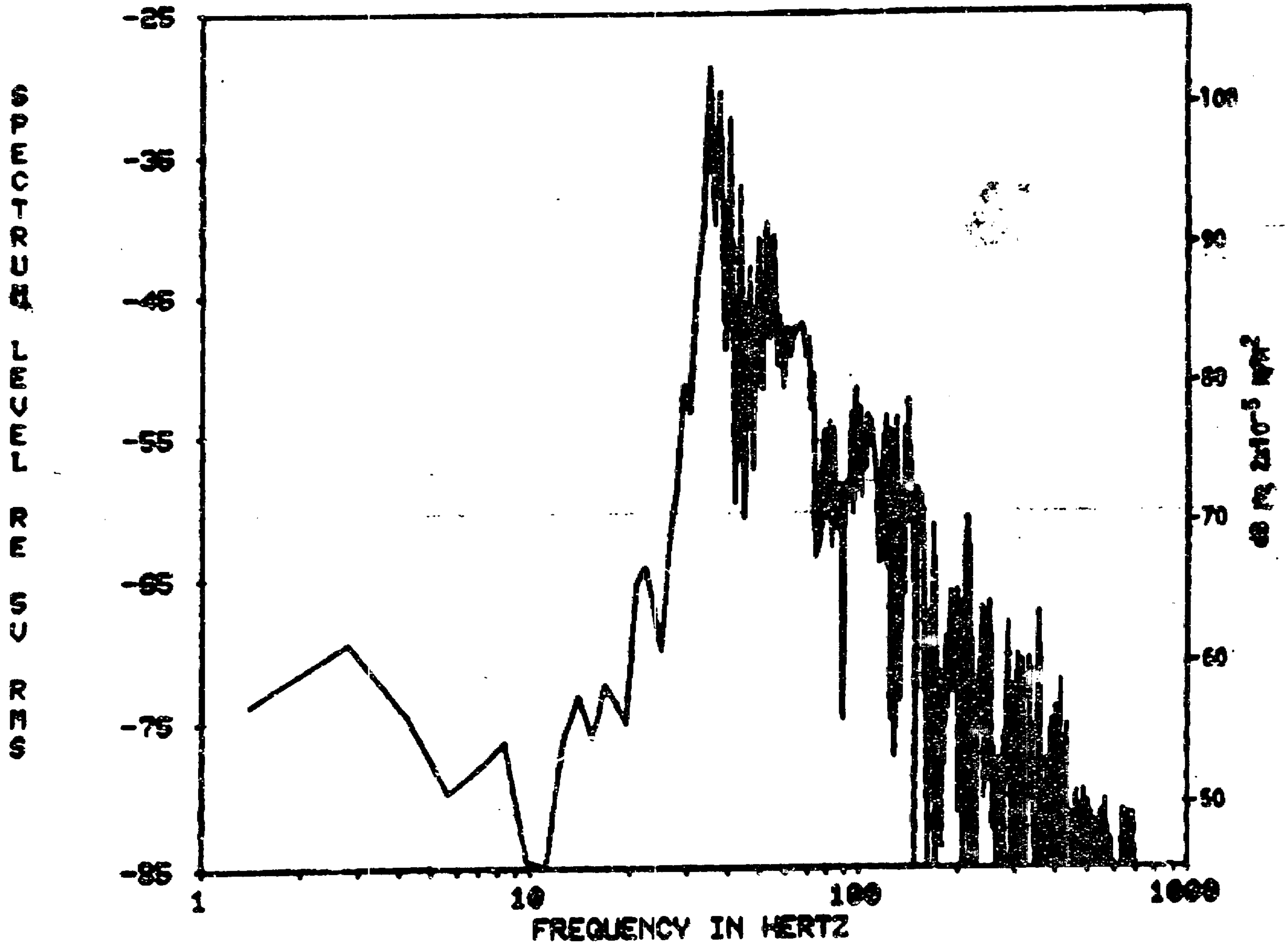


FIGURE 4-C. Fourier Transform - Family 2.

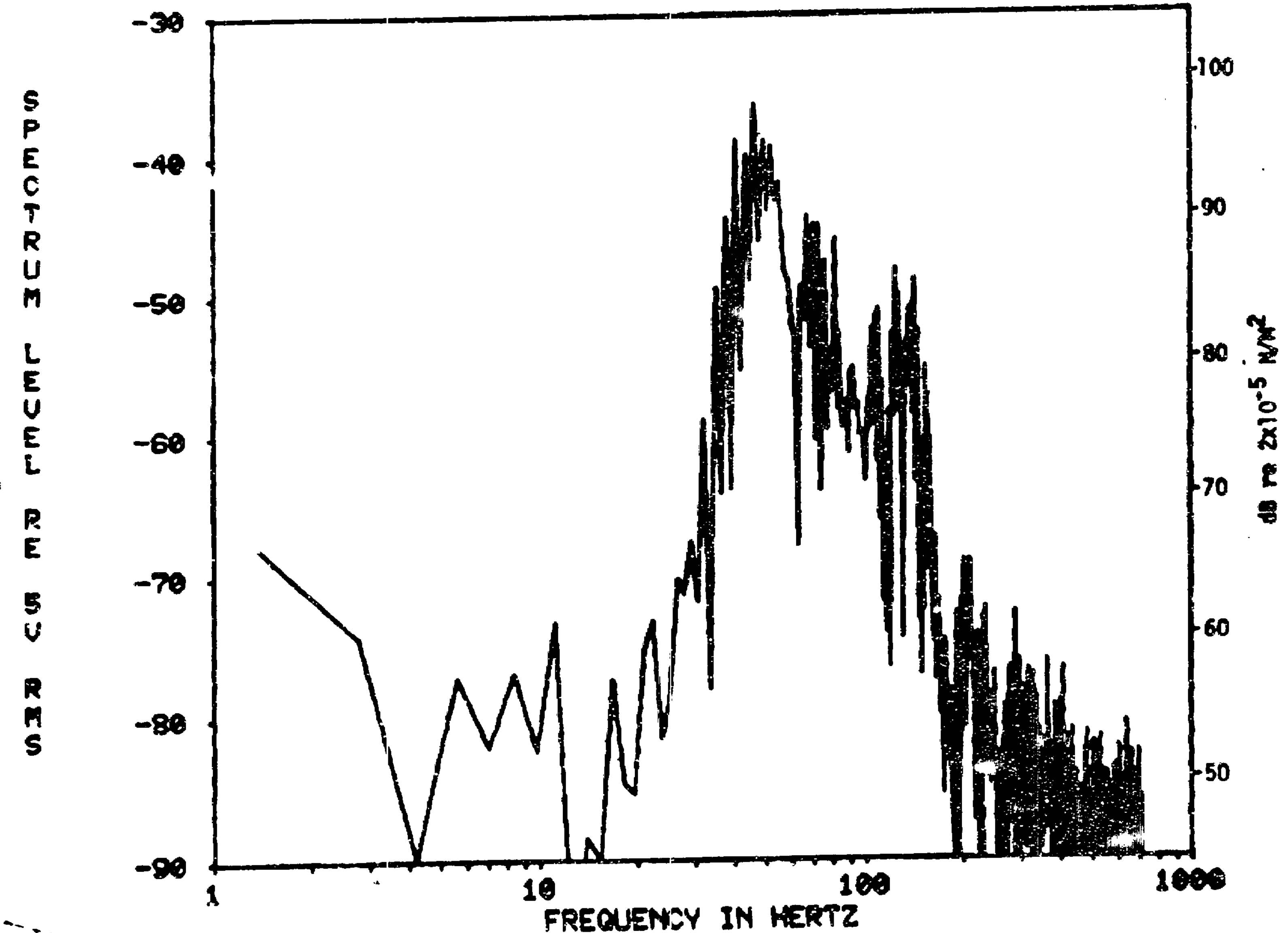


FIGURE 4-D. Fourier Transform - Family 3.

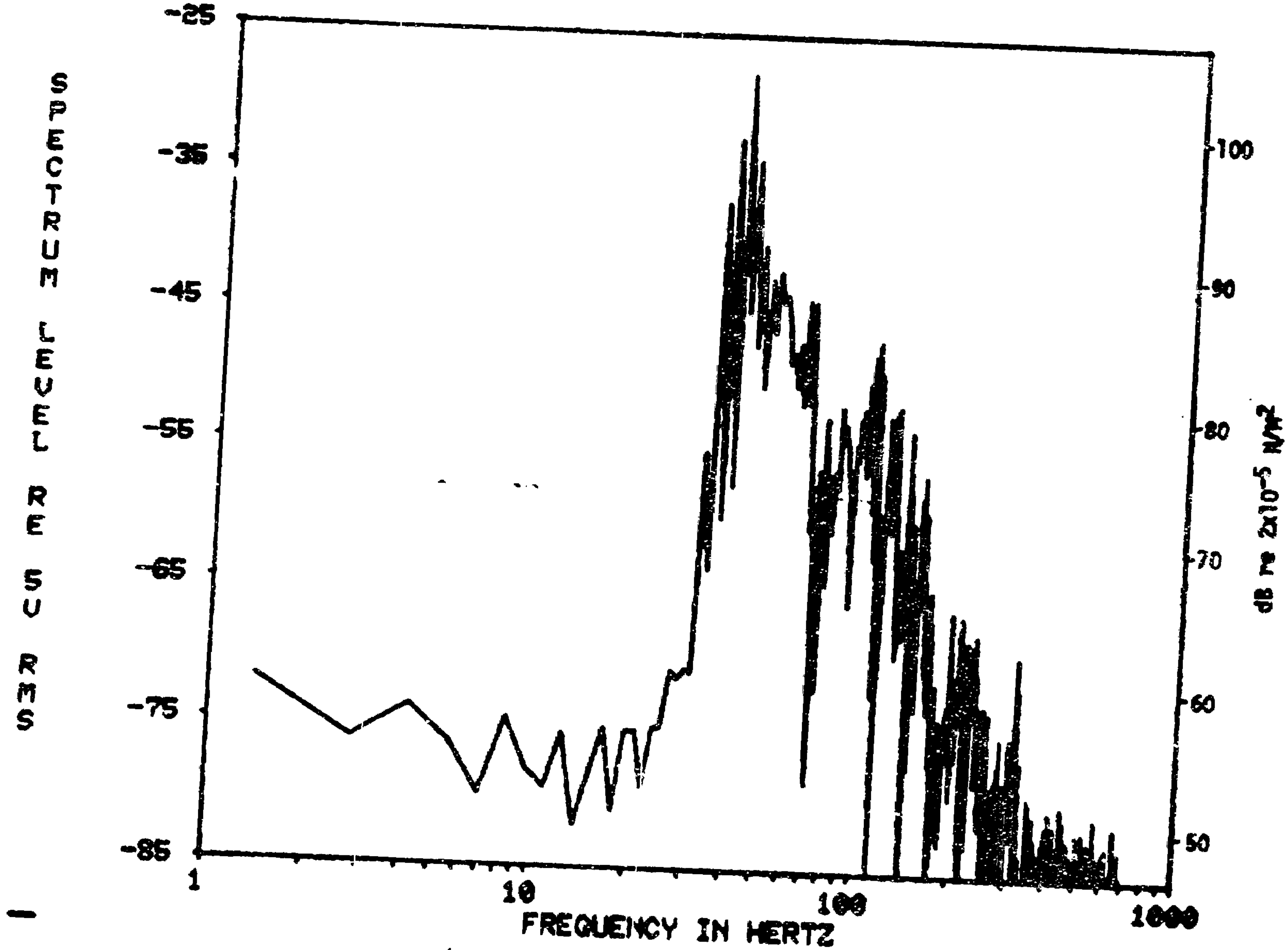


FIGURE 4-E. Fourier Transform - Family 4.

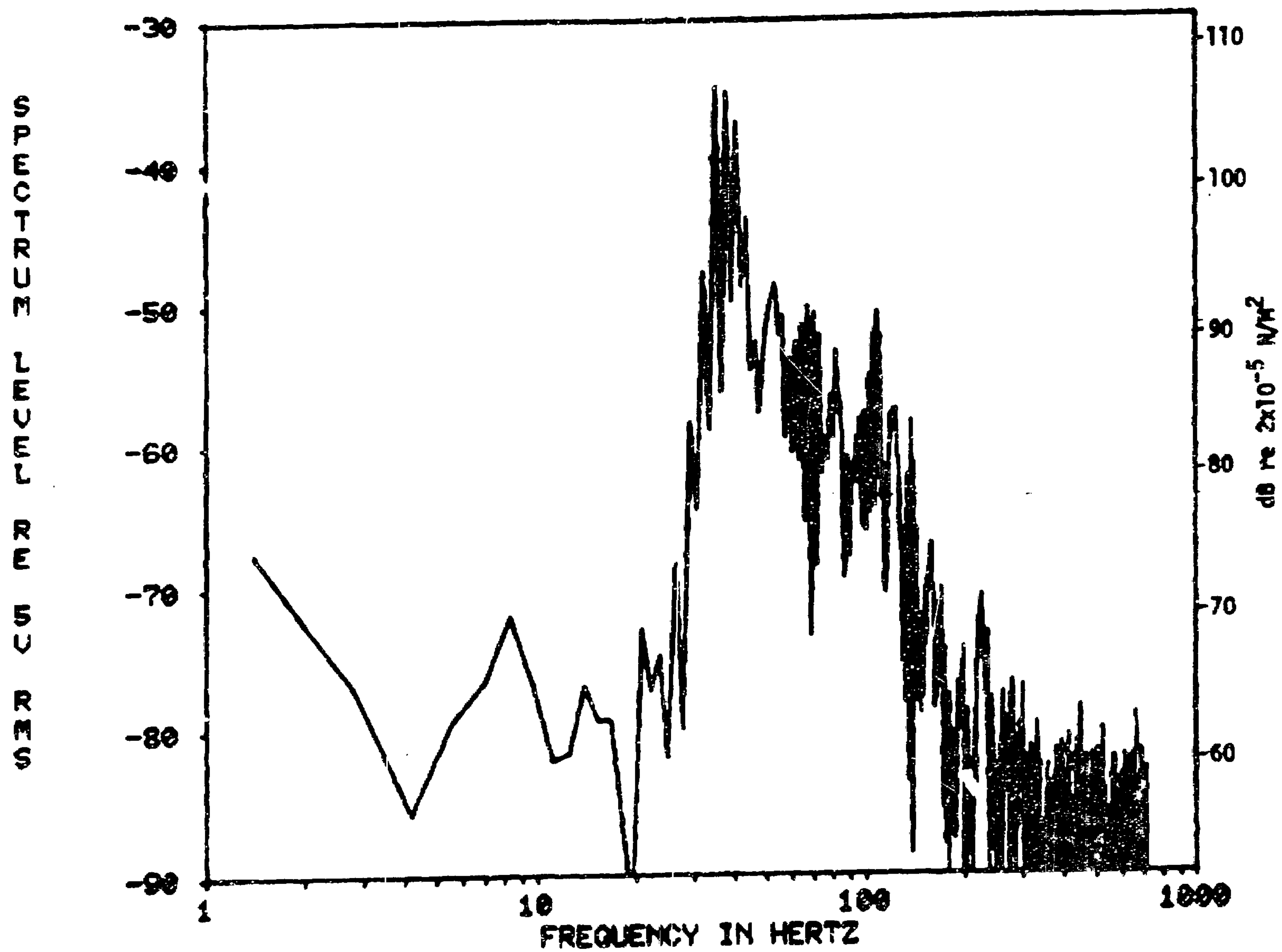


FIGURE 4-F. Fourier Transform - Family 5.

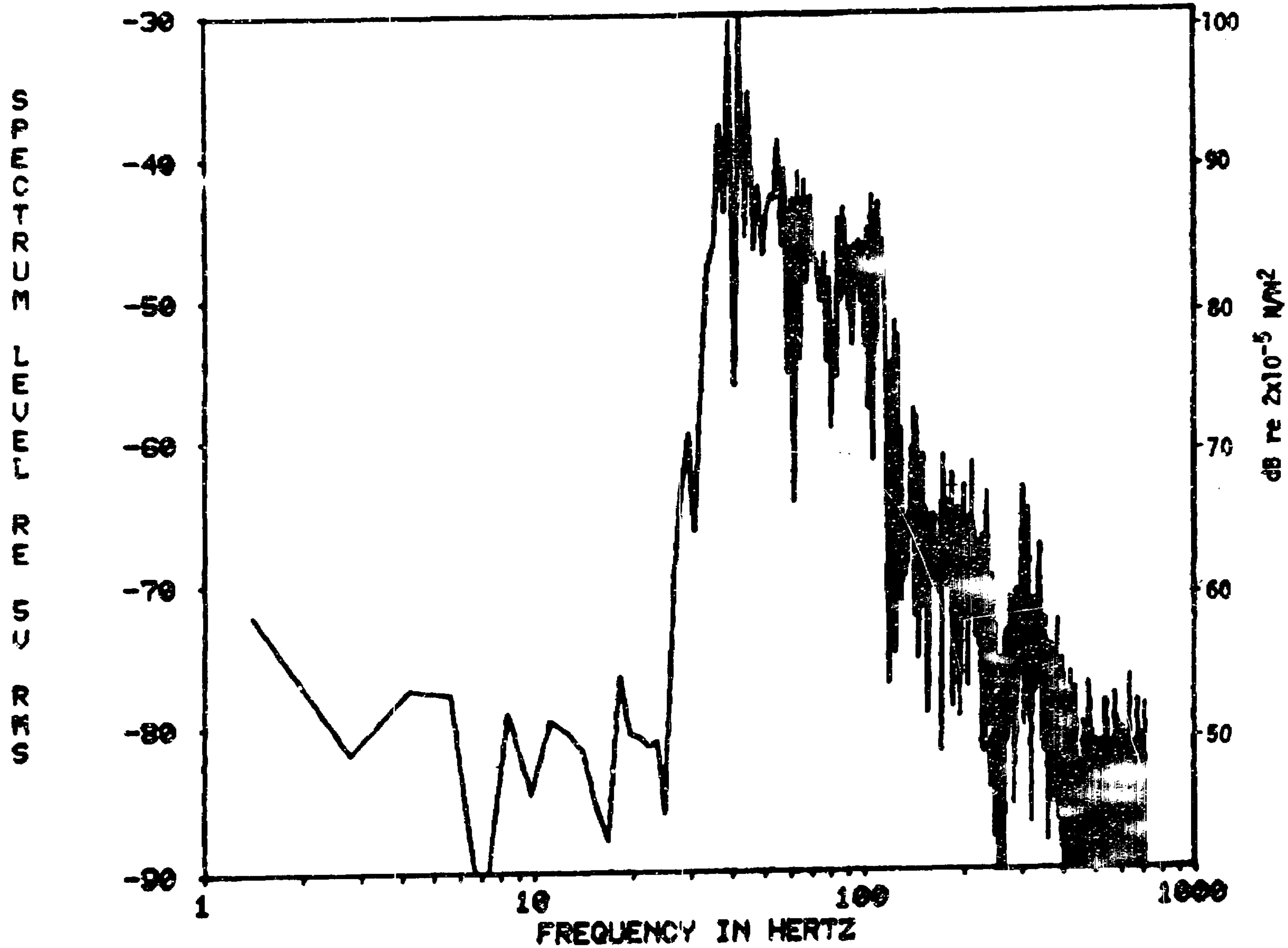


FIGURE 4-G. Fourier Transform - Family 6.

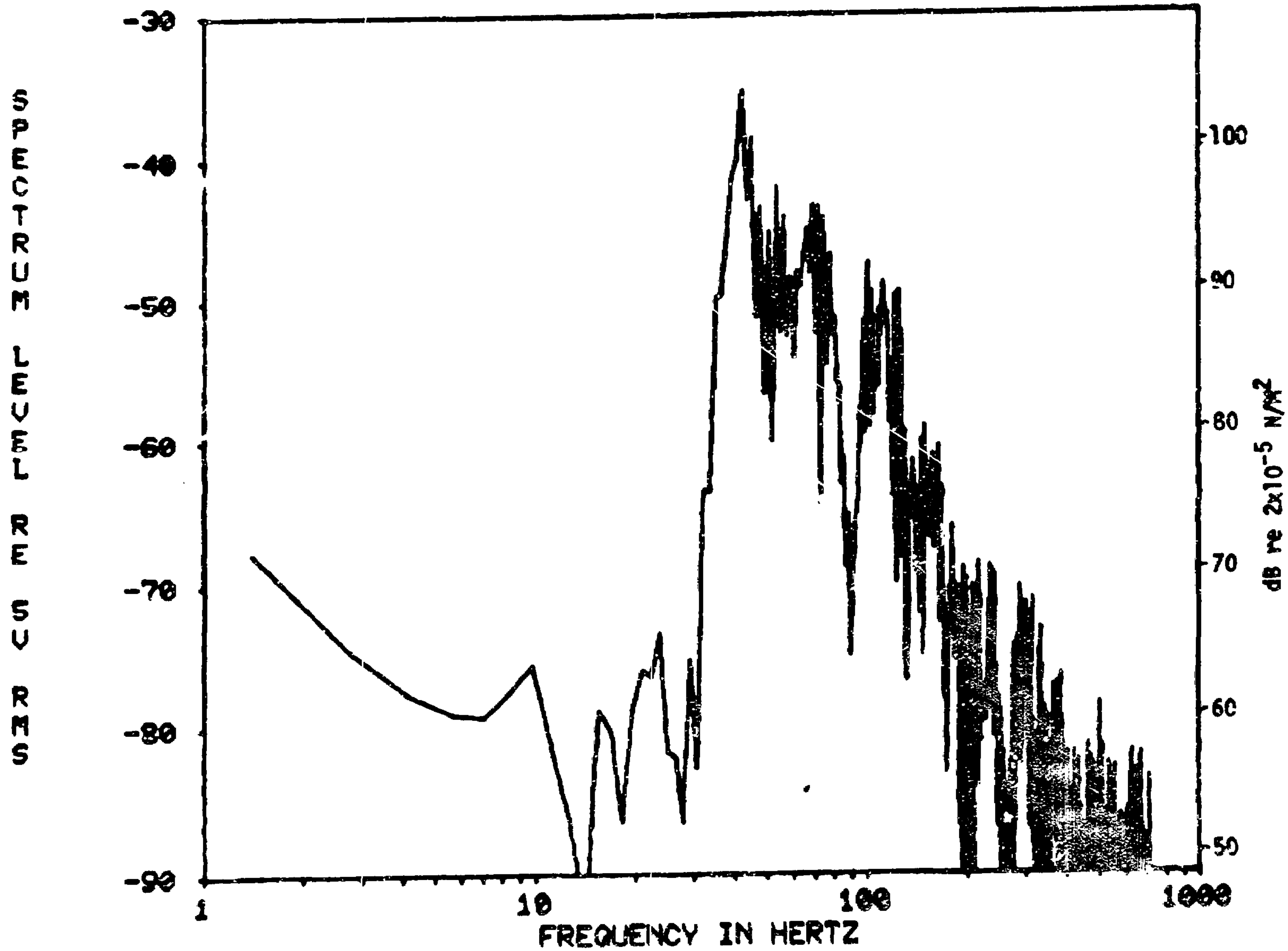


FIGURE 4-H. Fourier Transform - Family 7.

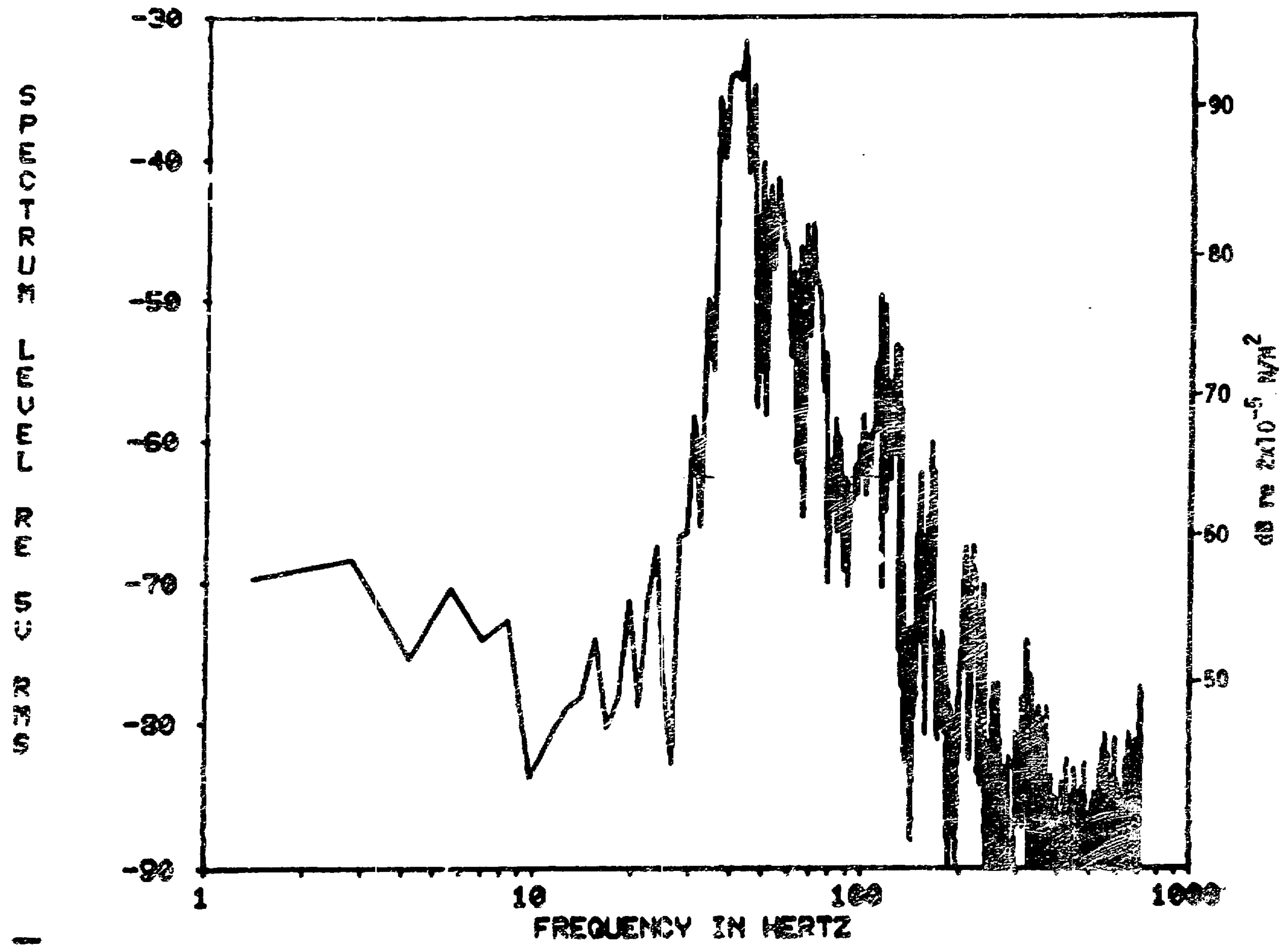


FIGURE 4-3. Fourier Transform - Family 8.

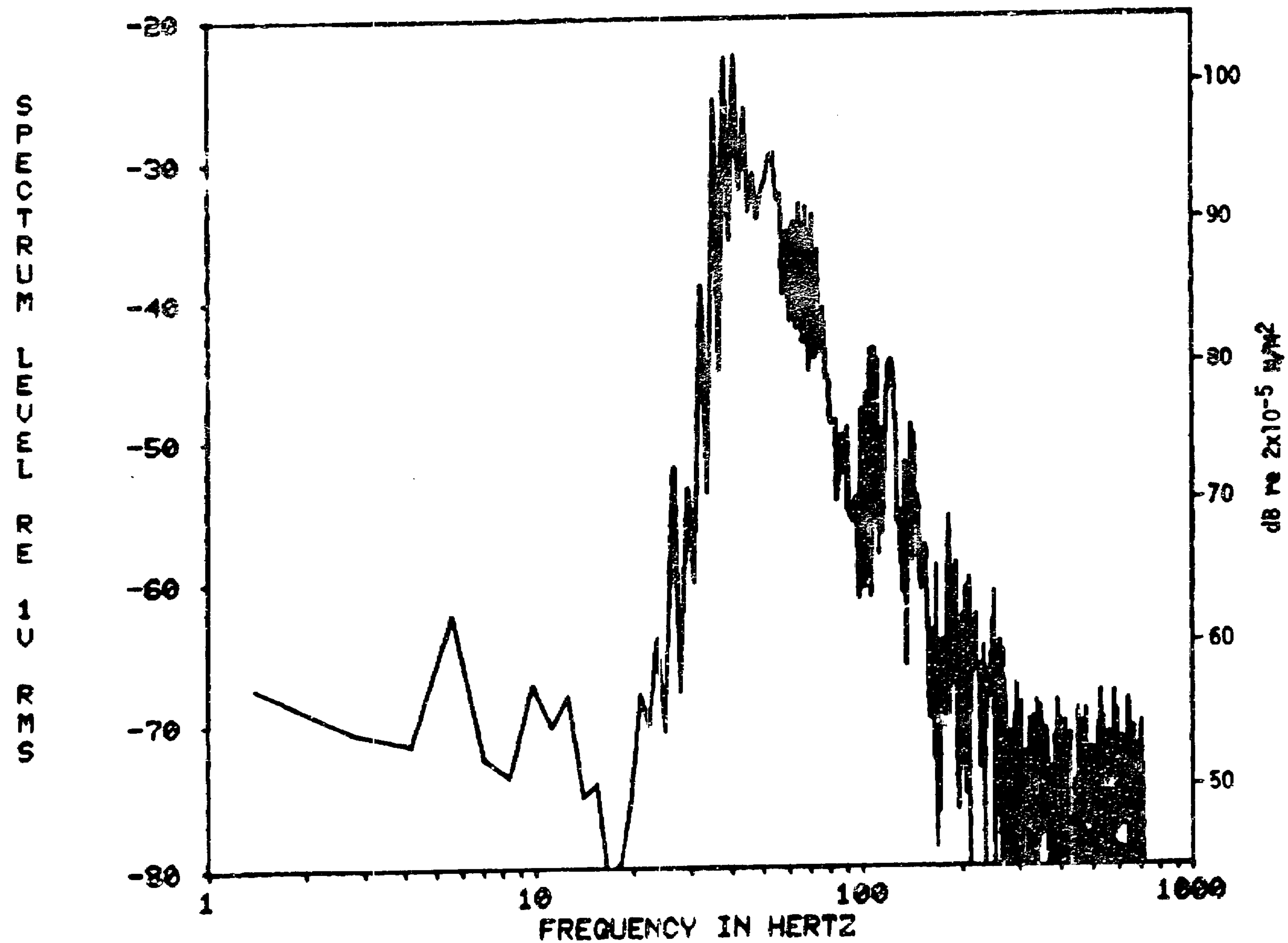


FIGURE 4-K. Fourier Transform - Family 9.

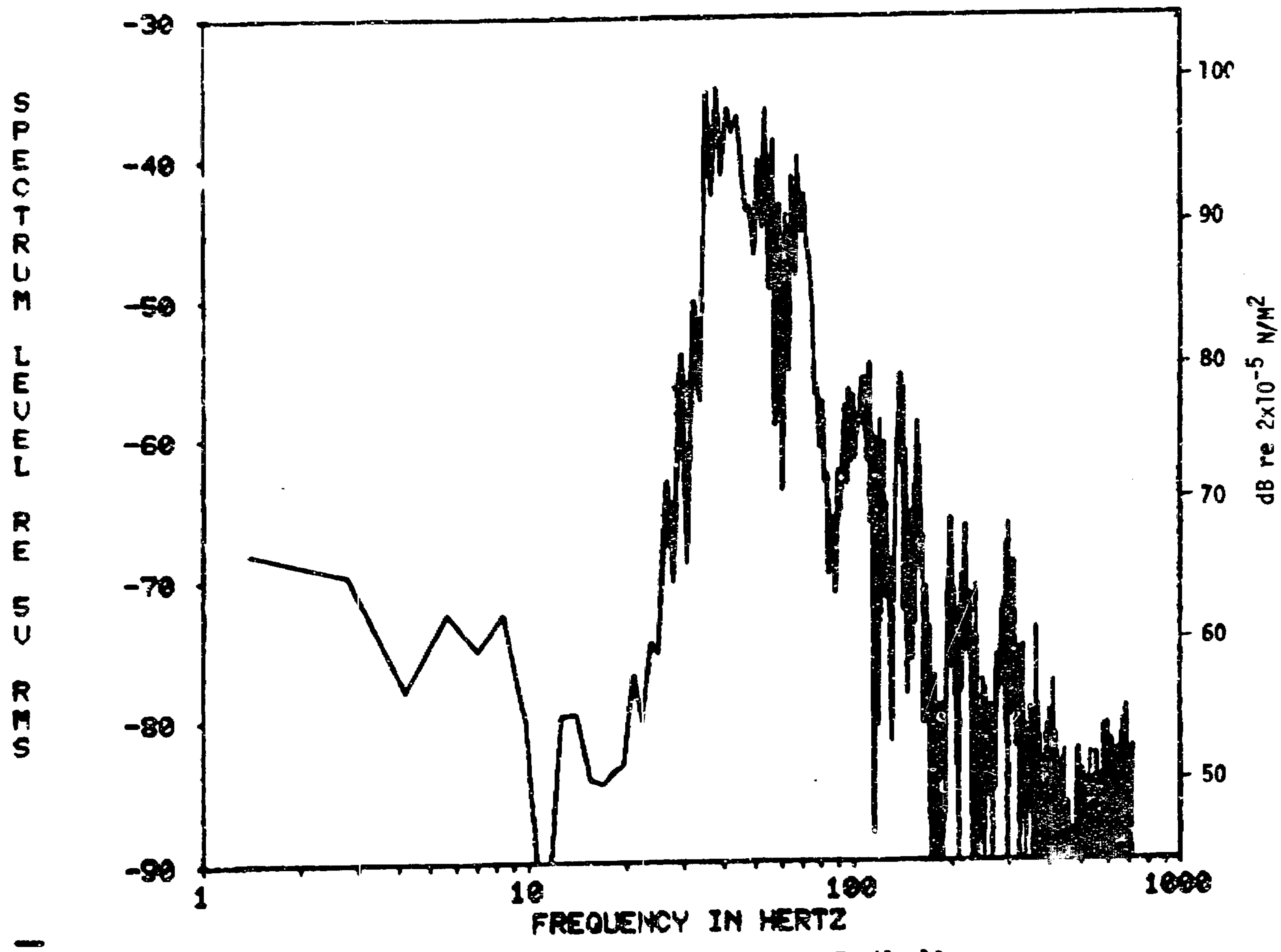


FIGURE 4-L. Fourier Transform - Family 10.

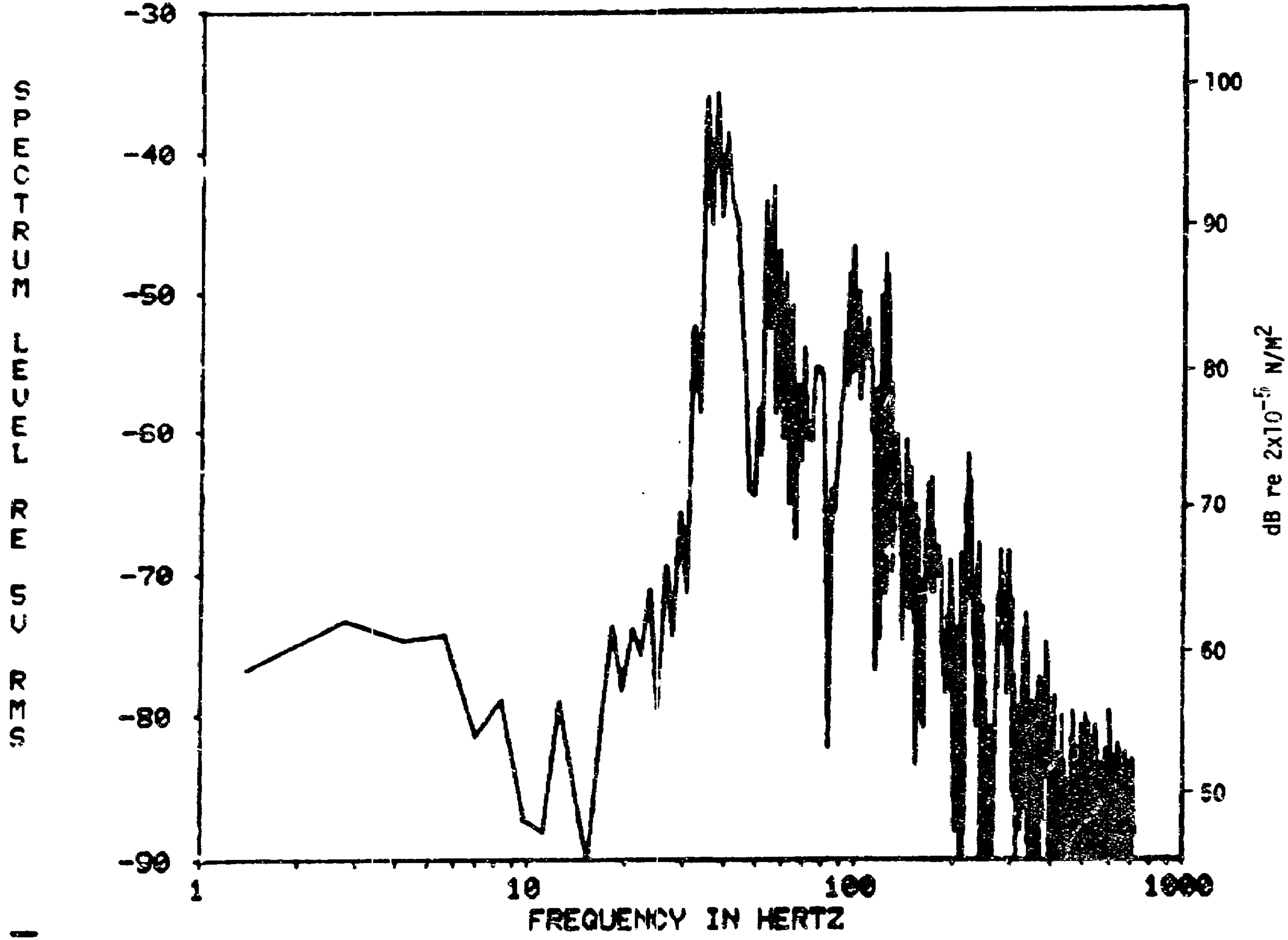


FIGURE 4-M. Fourier Transform - Family 11.

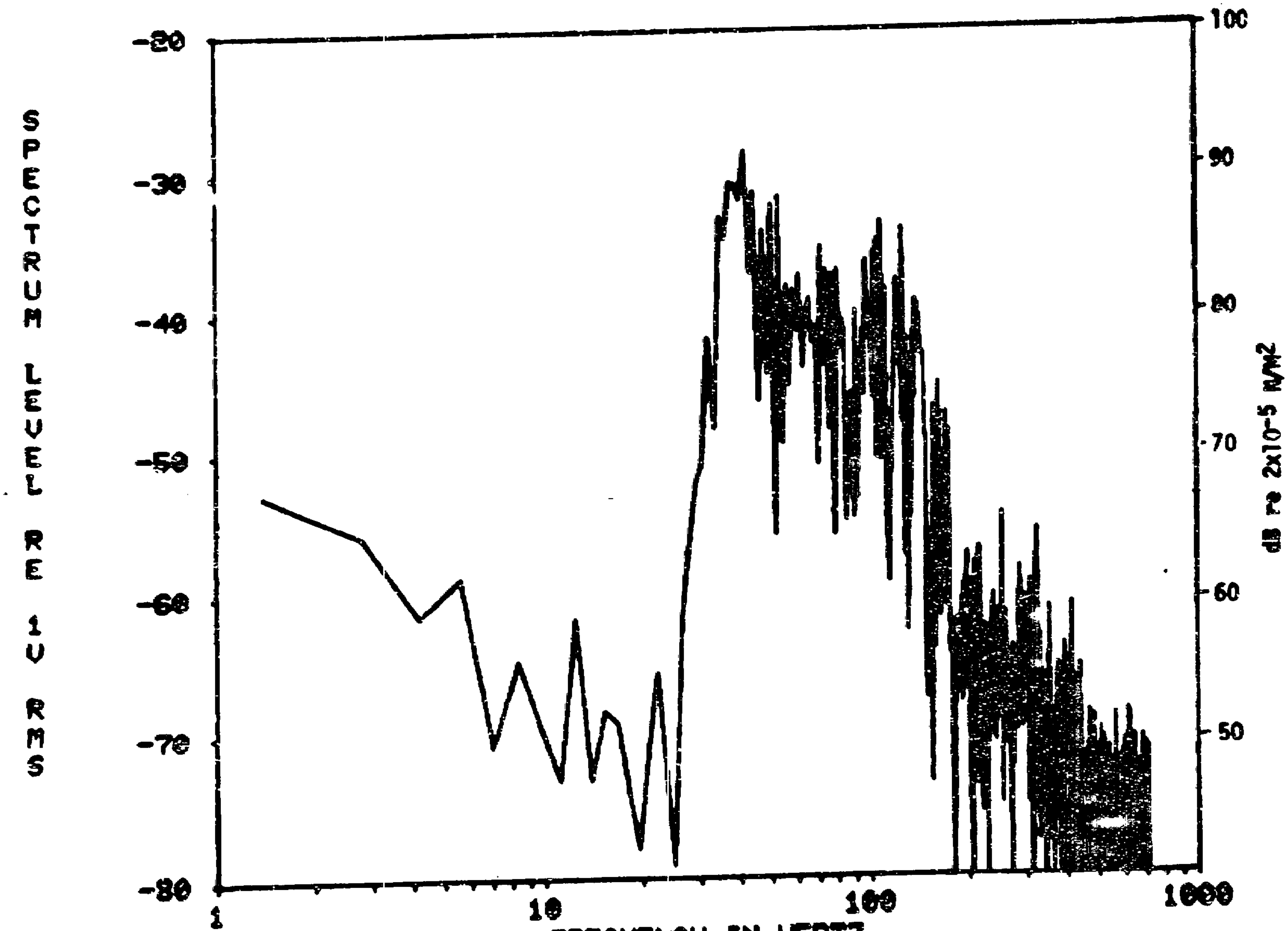


FIGURE 4-N. Fourier Transform - Family 12.

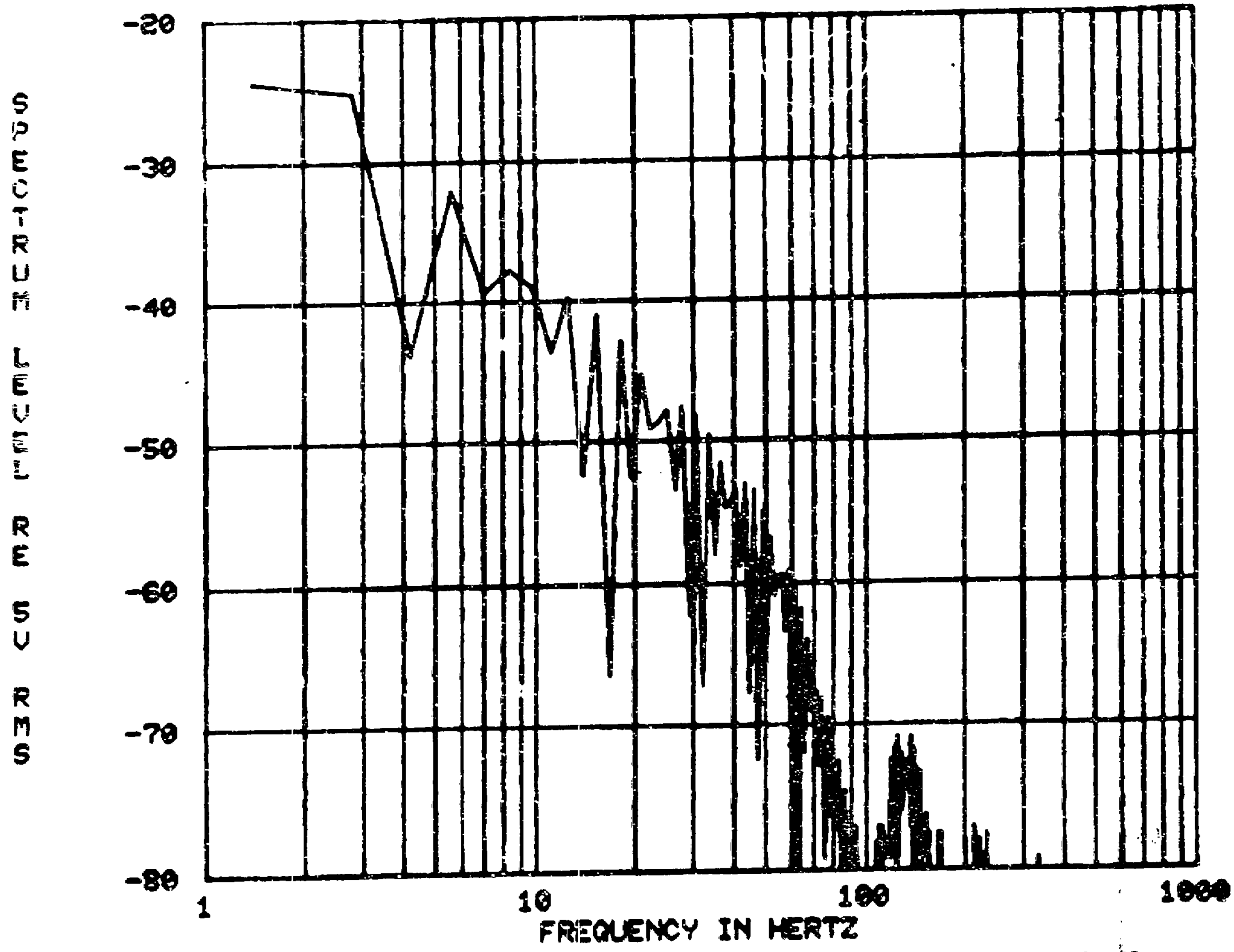


FIGURE 4-P. Measured Fourier Transform of electrical N-wave, D=.35 and R=.01 sec.

4. REFERENCES

4-1. HIGGINS, T. K. and CARPENTER, L. K., "A Potential Design Window for Supersonic Overflight Based on the Perceived Level (PLdB) and Glass Damage Probability of Sonic Booms", FAA-RD-73-116, July 1973.

5. HUMAN RESPONSE RESULTS

As suggested in section 2.3., "Dependent Measures", establishing a threshold of acceptability for commercial aircraft sonic booms would emphasize category scaling but from several points of view. Thusly, this section is reported in three parts. The first part summarizes the results from the Daily Noise Schedule category types of items, the second part gives the results of the Weekly Noise Schedule, while the third part presents the results based on the Magnitude Estimation Judgments from item "B" of the Daily Noise Schedule.

5.1. Daily Noise Schedule Results

For the questions that required a "Yes" or "No" response, results are given in Table 5-1 as percent responding "Yes" to a particular question. Going over the first question in detail will make the table clearly understandable. The first column provides the number of the question while the second column gives the question. For the first question we have, "Did any of the sounds . . . startle you?" The next seven columns provide percent of responses that were "Yes" for the various described conditions. Average boom levels, based on all homes, are given using Stevens' Mark VI calculation procedure for determining loudness level and thusly describe Conditions A, B, and C with 30 booms per day and Conditions D and E where there were 15 booms per day at the middle and low levels. The next to last column gives the average percent for the three conditions with 30 booms per day while the last column provides the percent of "Yes" answers based on all five conditions. The intent for the last two columns is to permit relatively ea., comparisons among the various questions. For the startle question, some 68% reported that they were startled by the high level boom (95.6 dB(Mark VI)) when presented 30 times per day. For the middle level boom (90.7 dB(Mark VI)), the percent reporting startle drops to 49%. With the level at 86.7 dB(Mark VI) and number of booms remaining at 30 per day, some 30% report that they are startled by this low level signal. When the number of booms is reduced to fifteen for the middle and low levels, the percent of responses is further reduced to 30% and 17% respectively. For the next to last column which gives the percent of "Yes" answers based on all three levels with 30 booms per day, 53% of the total reported being startled while 46% reported "startle" based on all five conditions. It is concluded that "startle" is decreased as both level and

TABLE 5-1. Summary of responses to Daily Noise Schedule (percent responding "Yes" to question).

NO.	QUESTION — Stevens' MARK VI→	30 BOOMS 95.6	30 BOOMS 90.7	30 BOOMS 86.7	15 BOOMS 90.7	15 BOOMS 86.7	AV.% 30 BOOMS	AV.% ALL
A1.	Startle you?	68	49	42	30	17	53	46
2.	Keep you from going to sleep?	4	3	0	0	0	2	2
3.	Wake you up?	31	32	22	10	10	28	24
4.	Interfere with listening to TV, radio, records, or tapes?	10	10	7	0	0	9	7
5.	Make the TV picture flicker?	9	1	1	3	0	4	3
6.	Make the house vibrate or shake?	76	73	29	70	30	60	57
7.	Interfere with conversation?	35	21	13	0	10	23	19
8.	Interfere with a telephone conversation?	16	11	6	0	0	11	9
8a.	If "NO", Did any noises occur while using the phone?	51	48	43	23	30	48	43
9.	Disturb your rest or relaxation?	18	18	6	7	3	14	12
10.	Interfere with or disturb any other activity?	16	10	9	17	3	11	11
11.	Bother, annoy, or disturb you in any other way?	12	5	3	0	0	7	5
C.	In respect to your child (children), was there any indication that the sounds							
1.	Startled him (her) (them)?	51	32	23	30	3	35	31
2.	Kept from going to sleep?	16	14	4	0	3	11	9
3.	Awakened him (her) (them)?	25	23	14	3	3	21	17
4.	Interfered with or disturbed any other activity? (Recorded two)	10	11	13	0	0	11	9
F1.	Were there other sounds which you heard in your home that bothered or annoyed you as much as the sounds we played?	26	4	12	27	23	14	16
2.	Any sounds that bothered you more than the sounds we played?	31	30	39	17	30	33	31

number are reduced and that of the eighteen questions of Table 5-1, A1, A6, and A8a tended to produce a larger percent of "Yes" responses than the remaining fifteen questions (note results in last two columns).

Turning to the results for the remaining items of Part A, items 2 through 11, for item 2, there is only a slight tendency for the booms to keep the main participant (the wife) from going to sleep. This is not surprising as the booms were presented during the daytime period only. To item 3, there was an increased tendency to be awakened by the booms over interference with going to sleep (item 2) but this decreased to 10% for both the middle and low level booms when presented fifteen times per day. Note that both the high and middle level booms when presented thirty times, provoked approximately the same extent of waking response, roughly 30%.

For items 4 and 5 of part A, percent was at a low level for those reporting interference with listening activities such as TV or radio, and making the TV picture flicker. Nine percent reported flickering of the television picture for the high level booms which was unexpected.

The highest response level was to item 6, which solicited information relative to whether-or-not the booms caused the house to vibrate or shake. Seventy to seventy-six percent responded that the booms caused the house to vibrate or shake when presented at the middle or high levels and regardless of the number of booms presented. Approximately 30% reported house vibration and shaking as a result of the low level booms (86.7 dB(Mark VI)). From the point of view of obtaining evidence that we were utilizing a realistic simulation approach, the high percentage of participants reporting house vibration and shaking phenomena was gratifying. However, this result is not particularly useful when exercising the problem of establishing a threshold of acceptability for sonic booms. The fact that the booms caused the house to shake, does not necessarily mean that the noise or the shaking of the house are particularly disturbing to the participant. Fortunately, results relevant to how much the house vibrations annoyed or disturbed are available from the Weekly Noise Schedule and will be presented in its section.

The next three items (A7, 8, and 8a) deal with interference with speech activities. The high level booms (95.6 dB(Mark VI)) produced interference with conversation for 35% of the wives while

the middle and low level booms provided zero and 10% interference respectively for the two conditions using fifteen booms per day. The 10% interference for the low level over the 0% for the middle level is one of the few anomalies observed in the results. Consequently, we look on it as just that, an unusual occurrence due to chance or error and conclude that from the standpoint of NOT interfering with conversation that either the middle or low level is acceptable when presented fifteen times per day. Interference with telephone use was minimal. It was at a sixteen percent level for the high level booms and dropped off to zero for the middle and low level booms when presented fifteen times per day. Question 8a is the only question where a high percent has a positive meaning. Our interest was in whether-or-not the participants were using the telephone at the time that a boom signal was presented. Consequently, for those responding "No" to 8 (interfere with a telephone conversation), we asked them if they were talking on the telephone at the time that a signal presented itself. The percents to 8a provide information regarding those who were using the telephone at the time a boom occurred but the boom did not interfere with the conversation. Using the results for the high level boom as an example:

- Sixteen percent reported that they were using the telephone at the time a boom occurred and that the boom interfered with their telephone conversation.
- Fifty-one percent reported that they were using the telephone at the time a boom occurred and the boom DID NOT interfere with their telephone conversation.
- This would mean that thirty-three percent did not use the telephone at the time that booms occurred.

The last three questions of part A (questions 9, 10, and 11) can be discussed as a group. Question 9 deals with interference with rest and relaxation. There is minor disturbance reported for the low level booms for either 30 or 15 daily presentations (6% and 3% respectively) as well as for the middle level boom when presented 15 times per day (7% report disturbance). Items 10 and 11 provide an opportunity to report interference or annoyance with activities not given in the preceeding questions. It is clear that interference with activities that persons are expected to recall is minimal and particularly for the low level boom presented fifteen times daily. Some of the activities reported for these two items

were reading, ironing, eating, playing games, sewing, and so on.

Part C of the Daily Noise Schedule requested the main participant to rate their children on four items (See Table 5-1). For the high level boom, 51% rated their children as being startled by the booms while at the low level (86.7 dB(Mark VI)) presented 15 times per day, only 3% noticed that the children were startled by the booms. Note that adults reported a greater startle response for themselves than for their children (compare A1 results to C1 results). For all four items relative to the children, it is clear that the low level boom presented fifteen times per day would be considered in an acceptable range.

The two questions in part F attempted to obtain information relative to:

1. Were there other sounds in the home that bothered or annoyed as much as the booms?

2. Any sounds which bothered or annoyed more than the booms?

As can be observed from the results in Table 5-1, question 1 did not elicit an expected sequence of responses. As the booms decrease in level, we would expect the number of other noises that bothered or annoyed as much as the booms to increase. This did not occur. One possibility is that it was difficult for the subjects to rate other noises in the home as being as equally bothersome or annoying as the booms. It is quite possible that we asked a question that was too difficult. On the other hand, the results to F2 are less inconsistent, for the low level booms at both 30 and 15 daily presentations, the percent of noises in the home that were more annoying increased as expected. The main point is that at least 30% of the subjects reported noises in the home that were more annoying than even the high level booms. This topic will be discussed more fully in the next section and examples of sounds that were more annoying than the booms will be given.

Table 5-2 gives the main participants' ratings on a five-point scale. The results are encouraging in that some 92% find the middle level boom as "Moderately, Very little, or Not at all" annoying when presented 30 times a day and the percent increases to 97% for the middle level at 15 booms per day. Accepting this result at at its face value, one could comfortably contend that booms at a level of approximately 90 dB(Mark VI), as experienced in the home, would be acceptable for single family living.

TABLE 5-2. Summary of responses to Question D of Daily Noise Schedule (percent responding to various categories).

D. Now I would like for you to rate the sounds on a 5-point scale as to how much they annoyed or disturbed you?

HOW MUCH DID THE SOUNDS ANNOY YOU?	30 BOOMS PER DAY			15 BOOMS	
	95.6	90.7	86.7	90.7	86.7
a. Almost Intolerable	4	1	0	0	0
b. Very Much	16	7	0	3	0
c. Moderately	29	26	10	30	0
d. Very Little	36	41	40	40	50
e. Not At All	15	25	50	27	50

Table 5-3 gives the results to Part E of the Daily Noise Schedule. If persons rated the booms as, "Almost intolerable, Very much annoying, or Moderately annoying" in Part D, they were asked to give the time of day that they were annoyed. There was interest in the idea that there may be greater annoyance to the signals in the evening when families are presumably relaxing and resting. Examination of Table 5-3 shows that such a situation did not occur. When results of the first three categories of Table 5-2 are divided

TABLE 5-3. Breakdown by time periods of percents annoyed (Part E of Daily Noise Schedule).

	30 BOOMS PER DAY									15 BOOMS PER DAY					
	95.6			90.7			86.7			90.7			86.7		
	*M	A	E	M	A	E	M	A	E	M	A	E	M	A	E
Almost Intolerable	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0
Very Much Annoyed	4	6	6	5	0	2	0	0	0	3	0	0	0	0	0
Moderately Annoyed	10	9	10	12	5	8	7	1	2	13	13	4	0	0	0

* M means Morning (0700-1200)
A " Afternoon (1200-1700)
E " Evening (1700-2200)

into morning, afternoon, and evening time periods as shown in Table 5-3, the persons reported little difference between the periods and, if anything, tended to report more annoyance during the morning period when compared to both afternoon and evening.

5.2 Weekly Noise Schedule Results

The combined responses of both adult members of the family are given in Table 5-4. The percents are for those responding "Yes" to the various questions. The results are in the same format as those from the Daily Noise Schedule and the two sets can be directly compared. As for the daily schedule, the two questions which dominate relative to possible unacceptability are, A1. which asks whether-or-not the booms produced startle, and A6. which asks if the booms make the house vibrate or shake. For the startle question, there is a slightly increased tendency to report startle on the weekly schedule. If we look at the sequence of results by conditions (left to right) from the daily schedule, they are: 68, 49, 42, 30 and 17% respectively. The corresponding results for the weekly schedule are: 67, 56, 47, 30, and 30%. A comparison of responses to A6 shows 76, 73, 29, 70, and 30% for the reporting sequence of the five conditions from Table 5-1 (daily schedule), while the same sequence of conditions for the weekly schedule is, 93, 81, 47, 60, and 30%. More house vibration and shaking is reported on a weekly basis, particularly for the three conditions with 30 daily boom presentations. The results presented in Table 5-4 can be examined in more detail but the more important question is the extent that the persons were annoyed or disturbed by being startled, noticing that the house was made to shake, and so on.

Ratings on a five-point scale for those who responded "Yes" to the items of Part A are given in Table 5-5. If the participant indicated some interference or disturbance relative to one of the eleven items of Part A, they were then asked to rate extent of annoyance resulting from the interference or disturbance using:

a. Almost Intolerable
b. Very Much
c. Moderately
d. Very Little
e. Not At All

The percents of Table 5-5 are for these five categories. Since no participant utilized "a. Almost Intolerable" for any of the items relative to the five conditions studied, this category is not listed in the

TABLE 5-4. Summary of responses to Weekly Noise Schedule (percent responding "Yes" to question).

NO.	QUESTION / Stevens' MARK VI→	30 BOOMS			15 BOOMS		AV.% 30 BOOMS	AV.% ALL
		95.6	90.7	86.7	90.7	86.7		
A1.	Startle you?	67	56	47	30	30	57	48
2.	Keep you from going to sleep?	13	6	0	0	0	7	5
3.	Wake you up?	27	25	13	20	10	22	20
4.	Interfere with listening to TV, radio, records, or tapes?	20	6	7	0	10	11	9
5.	Make the TV picture flicker?	0	6	13	10	0	7	6
6.	Make the house vibrate or shake?	93	81	47	60	30	74	65
7.	Interfere with conversation?	27	19	20	10	0	22	17
8.	Interfere with a telephone conversation?	13	6	0	0	0	7	5
8a.	If "NO", Did any noises occur while using the phone?							
9.	Disturb your rest or relaxation?	7	6	0	0	10	4	5
10.	Interfere with or disturb any other activity?	0	13	7	10	0	7	6
11.	Bother, annoy, or disturb you in any other way?	13	0	7	10	0	7	6
F1.	Were there other sounds which you heard in your home that bothered or annoyed you as much as the sounds we played?	18	18	20	40	40	19	24
2.	Any sounds that bothered you more than the sounds we played?	55	45	70	80	80	56	62

table. The "No" rows of Table 5-5 provide the percents of persons reporting no interference or disturbance.

Breaking down the 67% (question 1) that reported a startle response to the 30 daily presentations of booms at 95.6 dB(Mark VI), 20% were "Very much annoyed", 27% were "Moderately annoyed", 20% reported that they were "Not at all annoyed", and the remaining 33% reported "No" startle. The remaining four conditions can be examined in the same manner. Note that for Condition C (30 booms per day at 86.7 dB(Mark VI)) that no one reports being "Very much annoyed" by being startled and 20% only are "Moderately annoyed". When the 86.7 dB(Mark VI) boom frequency is decreased to 15 daily exposures, we find that 10% only are moderately annoyed by their startle response, 20% report very little annoyance, and 70% show no startle response. Results to this item (1) show that reporting startle does not mean that a person is very much annoyed or disturbed by being startled. The results also indicate that an average boom level of 86.7 dB(Mark VI) occurring 15 times per day could be acceptable from the standpoint of experiencing startle.

Responses to questions 2 through 5 , which deal with interference with sleep, interference with listening activities, and flickering of the television picture, show little negative implications. If one were to choose an indoor design criteria level based entirely on these items, a very good case could be made for using the 95.6 dB(Mark VI) level with 30 daily presentations. At most, 7% responded that they were "Very much" annoyed to interference with these activities and as level was decreased, annoyance decreased.

Question 6 , which inquires whether-or-not the booms caused house vibration or shaking deserves careful scrutiny since some 93% responded "Yes" for the high level booms presented 30 times per day. Of these 93%, 13% reported being "Very much" annoyed, 3% were "Moderately" annoyed, 73% were "Very little" annoyed, and 3% used the "Not at all" annoyed category. Thusly, only 16% were "Very much" or "Moderately" annoyed by the observed house shaking of the high level booms. The percents drop as boom level is decreased until for the low level boom presented 15 times per day, 30% noticed that the booms shook the house but all were only "Very little" annoyed by this experience.

Questions 7 through 11 , as with questions 2 through 5 , have but slight negative implications. At most, 7% of the participants are "Very much" annoyed if there were interference with any

TABLE 5-5. Percents for annoyance categories from Weekly Noise Schedule.

	ANNOYED	30 BOOMS/DAY			15 BOOMS		AVG 1*	AVG 2+
		95.6	90.7	86.7	90.7	86.7		
QUES. 1	Very Much	20	9	0	0	0	10	7
	Moderately	27	16	20	20	10	21	19
	Very Little	20	25	20	10	20	22	20
	Not At All	0	6	7	0	0	4	3
	"NO"	33	44	53	70	70	43	52
QUES. 2	Very Much	7	0	0	0	0	2	2
	Moderately	0	0	0	0	0	0	0
	Very Little	7	0	0	0	0	2	2
	Not At All	0	6	0	0	0	2	2
	"NO"	87	94	100	100	100	93	95
QUES. 3	Very Much	7	0	0	0	0	2	2
	Moderately	0	6	7	0	10	4	5
	Very Little	20	6	7	20	0	11	11
	Not At All	0	13	0	0	0	4	3
	"NO"	73	75	87	80	90	78	80
QUES. 4	Very Much	7	0	0	0	0	2	2
	Moderately	0	0	0	0	10	0	2
	Very Little	13	6	7	0	0	9	6
	Not At All	0	0	0	0	0	0	0
	"NO"	80	94	93	100	90	89	9[illegible]
QUES. 5	Very Much	0	0	0	0	0	0	0
	Moderately	0	0	0	0	0	0	0
	Very Little	0	6	7	0	0	4	3
	Not At All	0	0	7	10	0	2	3
	"NO"	100	94	87	90	100	93	94
QUES. 6	Very Much	13	0	0	0	0	4	3
	Moderately	3	13	7	10	0	8	7
	Very Little	73	50	33	40	30	52	47
	Not At All	3	19	7	10	0	10	8
	"NO"	7	19	53	40	70	26	35

	ANNOYED	30 BOOMS/DAY			15 BOOMS		AVG 1*	AVG 2+
		95.6	90.7	86.7	90.7	86.7		
QUES. 7	Very Much	7	0	0	0	0	2	2
	Moderately	7	13	0	0	0	7	5
	Very Little	13	0	20	10	0	11	9
	Not At All	0	6	0	0	0	2	2
	"NO"	73	81	80	90	100	78	83
QUES. 8	Very Much	7	0	0	0	0	2	2
	Moderately	0	0	0	0	0	0	0
	Very Little	7	6	0	0	0	4	3
	Not At All	0	0	0	0	0	0	0
	"NO"	87	94	100	100	100	93	95
QUES. 9	Very Much	7	0	0	0	0	2	2
	Moderately	0	0	0	0	0	0	0
	Very Little	0	6	0	0	10	2	3
	Not At All	0	0	0	0	0	0	0
	"NO"	93	94	100	100	90	96	95
QUES. 10	Very Much	0	0	0	0	0	0	0
	Moderately	0	13	7	10	0	7	6
	Very Little	0	0	0	0	0	0	0
	Not At All	0	0	0	0	0	0	0
	"NO"	100	88	93	90	100	93	94
QUES. 11	Very Much	7	0	0	0	0	2	2
	Moderately	0	0	0	10	0	0	2
	Very Little	0	0	7	0	0	2	2
	Not At All	7	0	0	0	0	2	2
	"NO"	87	100	93	90	100	93	94

* Average of 30 booms/day.

\+ Overall average.

of these activities and all of these responses involve the high level booms presented 30 times per day.

Items comparable to the first nine items of Part A have been used extensively in American social survey investigations involving annoyance to aircraft noise (Ref. 5-1, p. 6). As for the five-point category scale utilized for this study, each item could be scored in intensity of reported annoyance from 1 to 5, leading to a maximum annoyance score of 45. Obtained scores were given the following meaning (Ref. 5-1):

- 1 to 9 equals no annoyance,
- 10 to 20 equals moderate annoyance, and
- 21 and greater equals high annoyance.

Table 5-6 gives the mean and range of scores for these first nine items for both husband and wife and for each of the five experiment conditions. None of the mean scores is greater than nine so, on the average, it could be concluded that our participants were not markedly annoyed by any of the experiment conditions.

TABLE 5-6. Mean and range of scores on Weekly annoyance test (9 items).

		30 BOOMS PER DAY			15 BOOMS	
Stevens' Mark VI→		95.6	90.7	86.7	90.7	86.7
Husband	MEAN	7.6	4.0	2.2	1.6	1.6
	RANGE	2-28	1-7	1-7	0-4	0-6
Wife	MEAN	6.8	7.1	5.4	3.8	2.6
	RANGE	4-9	2-12	0-13	0-7	0-9

As pointed out in the discussion concerning questions F1 and F2 when used with the wives in the Weekly Noise Schedule, the responses to F1 were not consistent. It was concluded that asking persons to rate other noises in the home that, "bothered or annoyed you as much as the sounds we played?", was too difficult. Consequently, we will examine only the responses to question F2 which asked the husbands if, "any sounds bothered you <u>more</u> than the sounds we played?". Based on the Daily Noise Schedule, to F2, wives reported 31, 30, 39, 17, and 30 percent for the five respective conditions while husbands reported 55, 45, 70, 80, and 80 percent for the five condi-

tions, respectively, but when questioned on a weekly basis. Even though the husbands were in the home less time than the wives, they clearly found more noises in the home that bothered them more than the booms than did the wives. For the high level booms presented thirty times per day, 55% of the husbands noticed noises that were more annoying than the booms while the wives were at 31%. For the middle and low level booms presented fifteen times per day, some 80% of the husbands reported that there were noises in the home that bothered them more than the booms. Some of the situations and noise sources that bothered more than the booms were, children-crying-fighting-screaming, rock music, leaky faucet, dishwasher, refrigerator, clothes dryer, cars, motorcycles, neighbor's hi-fi, neighbors, and phone ringing. It is clear that for many persons, routine, everyday noise events bother or annoy more than the booms presented.

The final three questions related to design and certification noise criteria for commercial supersonic aircraft are of a broader nature and require a prediction on the part of the participants. The three questions and responses to them are given in Table 5-7. If all participants were to respond "Yes-Yes-No" respectively, it could be concluded that that particular condition could be perfectly

TABLE 5-7. Percent responding "YES" to three key weekly items.

If the sounds you were exposed to this week were to continue indefinitely in your neighborhood, . . .

		30 BOOMS PER DAY			15 BOOMS	
	Stevens' Mark VI →	95.6	90.7	86.7	90.7	86.7
Would they be acceptable to you?	HUSBAND	36	73	80	80	80
	WIFE	18	70	60	80	80
	TOTAL	27	71	70	80	80
Could you learn to live with them?	HUSBAND	64	91	90	80	100
	WIFE	64	70	90	80	100
	TOTAL	64	81	90	80	100
Would you move to another neighborhood?	HUSBAND	45	27	20	20	-0-
	WIFE	82	20	20	20	-0-
	TOTAL	64	24	20	20	-0-

acceptable. For the low level boom presented 15 times per day, all persons did report that they could learn to live with the booms and that they would not move if the booms were to continue indefinitely in their neighborhood. For the first question, some 20% reported that they would not find these low level booms acceptable if they continued indefinitely in their neighborhood. Although perfection was not achieved relative to these three items, the responses do indicate that indoor booms at 86.7 dB(Mark VI) are very close to being acceptable to persons living in single family housing.

The final set of data from the Weekly Noise Schedule involves estimates that both husbands and wives made of how many booms that they experienced for each condition. As expected, the wives reported hearing more booms than did the husbands since they would be in the home a greater part of the time. As shown in Table 5-8, for the 30 booms per day conditions, the average experienced did not approach the actual number of 210 booms that were presented. Also, there was little relationship between number presented and the estimates of how many were experienced. Note that for the low level booms presented 15 times per day that the average number estimated by the wives was 117 booms while the maximum number that any could have experienced was 105 booms. These results suggest the

TABLE 5-8. Estimates of average number of booms heard per week.

	30 BOOMS PER DAY			15 BOOMS	
	95.6	90.7	86.7	90.7	86.7
HUSBAND	44	39	51	37	44
WIFE	134	97	96	93	117

conclusion that persons' estimates of number of noise intrusions experienced may be quite inaccurate; unless one is keeping a tally, the number of actual intrusions is not accurately recalled.

5.3. Magnitude Estimation Results

As part of the Daily Noise Schedule, each of the main participants was asked to rate the loudness of the booms experienced that day using S. S. Stevens' magnitude estimation scaling method (see Part B. of Daily Noise Schedule). As mentioned previously, these

main participants were briefly trained prior to the start of the program in magnitude estimation ratings using single event broad band noise. For the experiment proper, each main participant used the booms experienced during the first day of the test as their standard noise. This means that four of the subjects used the high level booms (95.6 dB-Mark VI) as a standard, four used the middle level booms (90.7 dB-Mark VI), and the remaining four persons used the low level booms (86.7 dB-Mark VI) as their standard. Six engineering calculation procedures were obtained from the 1/3-octave band and fast Fourier transform results as described in the preceeding section. Least-square, best-fit relationships between each engineering calculation procedure and the mean log. magnitude estimations were obtained; the relationships were obtained separately for those having the high level booms as a standard, those using the middle level booms, and the four persons using the low level booms as a standard. Rates of change of loudness were obtained for the three 30-boom conditions on the basis of an average rate of change of those obtained from the three magnitude estimation conditions (high level boom as standard, middle level boom as standard, and low level boom as standard). Using this mean rate of change for loudness and correcting each intercept so that the mean value of the engineering calculation procedure was equal to the mean magnitude estimation score, an equation based on all twelve main participants was obtained. Lines representing the six equations are given in Figure 5-A, and the equations relating the six engineering calculation procedures are presented in Table 5-9.

The equations relating the magnitude estimation judgments to the various engineering calculations procedures are based on the three 30 booms per day conditions only. The main interest in these results is the rate of change of loudness plus the relationships among the various engineering calculation procedures. Obtaining an accurate estimate of the rate of change of loudness has high utility; if the rate of change is relatively slow, some increase in boom levels over a threshold would not be as apparent as if the rate of change of loudness was on the fast side. The relationships among the various calculation procedures is important since if the correlations are high, standards can be set in terms of the calculation procedure that is the most economical and easiest to apply.

For the six engineering calculation procedures investigated, rate of change varies from 12.0 dB for dBA and PL_6 to 12.9 dB using PL_7 for doubling or halving loudness. These are definitely

TABLE 5-9. Equations relating mean log magnitude estimations to various engineering calculation procedures.

CALCULATION PROCEDURE	EQUATION
dBA	y = .0250(x) + .085
dBD	y = .0243(x) - .201
dBE	y = .0247(x) - .136
PNdB	y = .0243(x) - .246
$^{*}PL_6$	y = .0250(x) - .268
$^{**}PL_7$	y = .0233(x) + .063

* Stevens' Mark VI   ** Stevens' Mark VII

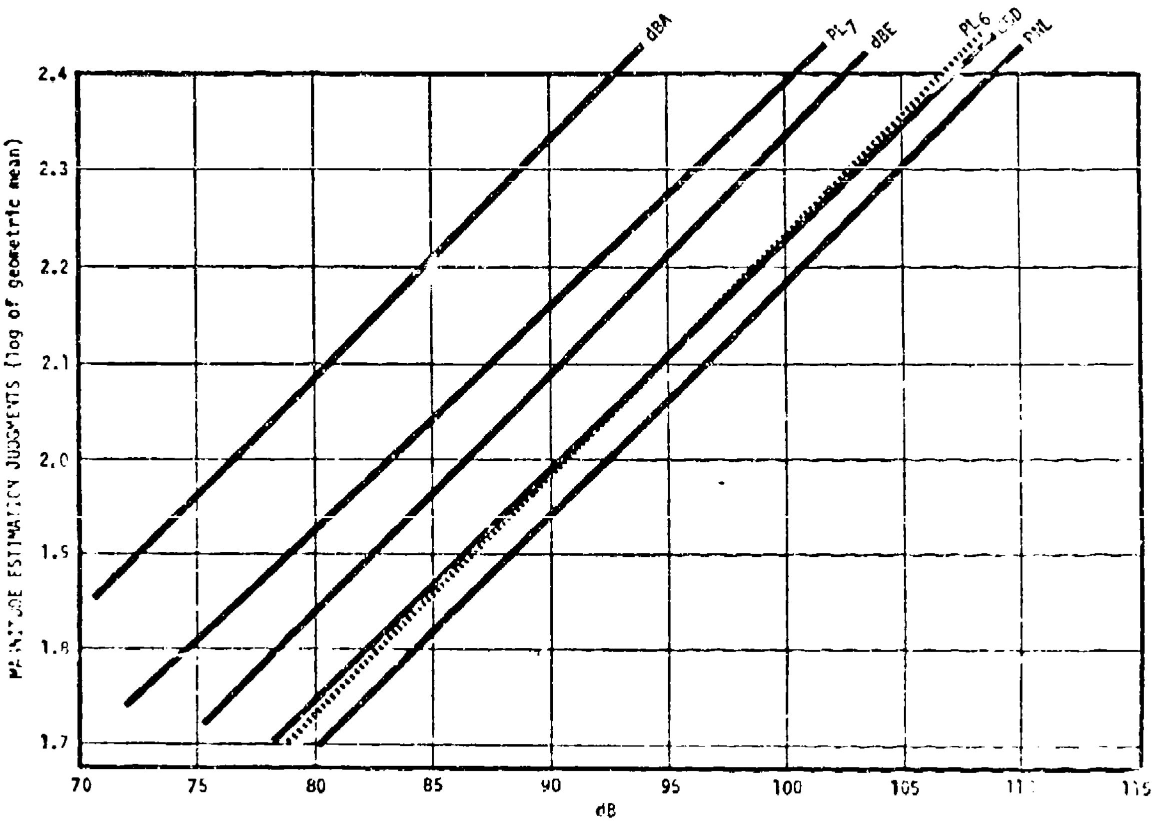


FIGURE 5-A. Relationship between magnitude estimation judgments and selected engineering calculation procedures (30 booms/day conditions).

on the slow side and for the most part can be attributed to those persons who were using the high level booms as their standard. On the other hand, rates of change using only the two points obtained from the two fifteen boom per day conditions were 5 to 6 dB for doubling or halving loudness. No definite conclusions can be drawn from these results but they do raise the possibility that rate of change in this real life setting interacts with number of booms presented. Loudness could increase faster for a lesser number of booms when persons are involved in their daily living activities.

The relationships among the various engineering calculation procedures are given in Table 5-10. Results indicate that all of the methods which depend on spectral characteristics are highly related and could function about equally well in establishing sonic boom standards.

TABLE 5-10. Product-moment correlations among various engineering calculation procedures.

	dBD	dBE	PNdB	PL_6	PL_7
dBA	.944	.989	.976	.963	.988
dBD		.976	.954	.951	.953
dBE			.986	.977	.990
PNL				.996	.987
PL_6					.979

5. REFERENCES

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6. RESULTS AND FINDINGS FROM PREVIOUS STUDIES

When drawing conclusions from an experiment that has an objective of:

Establishing a threshold of acceptability for commercial aircraft sonic booms,

there is high value in examining results from other human response studies as a means of checking on or confirming the obtained conclusions. Since this present study is a first in that it utilized a real life environment (families living in their homes) in conjunction with a controlled simulation approach, there are no studies which are comparable in even a general sense. From the standpoint of comparability, the studies that are closest to the present one are those that utilized a social survey approach in conjunction with overflights of military supersonic aircraft such as those completed in the 1960's in the Oklahoma City and St. Louis areas (References 6-1 and 6-2). However, the facts that only estimated overpressures are given as measures of the boom levels, that number of booms per day varied unsystematically (1 to 6 for the St. Louis study), that the boom signatures from military aircraft are not necessarily comparable to those expected from advanced commercial supersonic aircraft, and that the interviewees could have been preconditioned in the sense that they were expecting a negative experience (sonic booms), clearly indicates that comparisons should be made cautiously. Table 6-1 gives results from the St. Louis study (Ref. 6-2) for some inter-

TABLE 6-1. Comparison of percents reporting interference only for St. Louis study (0 to 4 miles, Av.PSF=1.60) and high level boom condition (95.6 dB-Mark VI).

NO.	ACTIVITY INTERFERENCE	ST.LOUIS RESULTS	DAILY RESULTS	WEEKLY RESULTS
A1.	Startled	72	68	67
3.	Sleep interrupted	52	31	27
4.	Radio and television	18	10	20
6.	House shaking	89	76	93
7.	Conversation interrupted	26	35	27
9.	Rest and relaxation interrupted	28	18	7

ference type of items that were also used in the present study plus results to those same items for the high level boom condition using both the Daily and Weekly Noise Schedule. Although the acoustical characteristics of the booms in the homes of the St. Louis interviewees could have been and probably were markedly different from those for the present study, some of the results are quite similar. For both "startled" and "house shaking", results are close for the two studies. Seventy-two percent of those exposed to the military aircraft booms reported startle interference while 68% and 67% reported a startle reaction for the Daily and Weekly Noise Schedule interviews. "House shaking" was 89% for the St. Louis study, and 76% and 93% for the present study. More "sleep interrupted", approximately 20% greater, was found from the military aircraft booms that for the simulated booms, but this could be a result of differences in sleeping times or time of boom presentation between the two studies. However, there is enough similarity between these two sets of results to suggest that simulated booms can produce results comparable to those obtained from human response studies involving military aircraft sonic booms. Also, on the basis of only those results presented in Table 6-1, the exact, same conclusion would be drawn from either study. The conclusion is, that the sonic booms from the military aircraft and those presented as the high level boom condition (95.6 dB-Mark VI) are both at too high a level to be regularly presented in dwellings.

Other human response studies that merit consideration are those completed in laboratory environments using small chambers or headphones in conjunction with electronic simulation of the booms, piston-driven devices which simulate sonic booms in a chamber or room (Ref. 6-3), and a shock-tube approach (Ref. 6-6). Again, there are many differences between these studies and the present study which emphasizes the real life living environment. Also, many of the laboratory studies were not aimed at obtaining a threshold of acceptability for design and certification purposes, but had as their objective the investigation of differences among various boom parameters such as rise time, overpressure, and wave forms, or the study of response sets such as annoyance vs. loudness judgments (Ref. 6-4). Other studies compared boom levels to those from subsonic aircraft noise and thusly were not directed to the problem of obtaining an acceptability threshold (Ref. 6-3). A laboratory study which was specifically directed at obtaining an absoluted acceptability level involving 100 persons concluded that indoor booms at approximately 90 PLdB using,

$$\text{PLdB} = 55 + 20 \log \frac{\text{Overpressure(PSF)}}{\text{Rise Time (secs.)}},$$

would be acceptable to 98% to 100% of the population (Ref. 6-5). Unfortunately, no octave or 1/3-octave band data is available for these simulated booms but the above equation used to estimate perceived level in PLdB has provided levels that are close to those obtained from 1/3-octave band data using Stevens' Mark VI or Perceived Noise Level in PNdB. For example, using results from one study with an outdoor boom rise time of 8 msec and with 1/3-octave band data obtained from "indoor" recordings, provides the levels for four overpressures of Table 6-2 (Ref. 6-6, p. A-3). As can be seen for this range of levels, the results based on the above equation are very good estimates of both Mark VI and Perceived Noise Level in PNdB. Since there is no other readily available approach for estimating the boom level of Reference 6-5 so that the obtained threshold of acceptability can be compared to that of the

TABLE 6-2. Comparison of Stevens' Mark VI and Perceived Noise Level (PNdB) to results obtained using equation of References 6-5 and 6-6.
(dBA Levels are also included for reference purposes)

OUTDOOR OVERPRESSURE	dBA	STEVENS' MARK VI	PERCEIVED NOISE LEVEL (PNdB)	EQUATION OF Refs. 6-5 & 6-6
.4 PSF	60.7	73.9	72.1	71.5
.8 PSF	66.7	79.0	78.4	77.5
1.6 PSF	72.7	84.1	84.8	83.5
3.2 PSF	78.7	89.3	91.0	89.5
MEAN	69.7	81.6	81.6	80.5

present study, the PLdB of the equation will be used as the best estimate. Since the boom level of Reference 6-5 that was judged acceptable is quite close to the boom level found acceptable in this study, it will be helpful to give the instructions used for the study of Reference 6-5. Note that the subjects are required to make a

INSTRUCTIONS FOR LABORATORY STUDY (Ref. 6-5)

"I am going to ask you to make judgments about some sounds. Please judge each sound separately. For each sound, think of the sound occurring twenty-five (25) times spread over your daily waking hours. If you believe that

you would accept this sound when experienced twenty-five times daily, press the button in your right hand. If you believe that you would not accept this sound, press the button in your left hand. Right hand means you would accept. Left hand means you would not accept. Remember, judge each sound by itself or separately. Now I'll give you two practice sounds. Are you all right?"

EXPERIMENT BEGINS

kind of prediction as to whether-or-not they could accept any one boom (in all, 64 booms were presented to each of 100 subjects), "twenty-five times spread over your daily waking hours". For most persons, this would be less than two booms per hour. However, it must be emphasized that there is a real difference between making such a prediction for each boom in a laboratory setting as opposed to actually experiencing the boom during their daily waking hours. Results from Reference 6-5 do tend to support those from the present study.

Results from a second laboratory study (Ref. 6-6) using a shock tube to simulate booms do not confirm those from either the present study or those of Reference 6-5 discussed above. Using twenty-one subjects judging thirty boom signals, approximately 93% of the judgments indicated acceptance of an "indoor" boom at a level of 68.8 dB using Stevens' Mark VI. As for the results of Reference 6-5, again the subjects are making a prediction as to how they would react to a number of booms heard on a regular basis but on the basis of hearing one boom in a laboratory setting. There are a number of possibilities relative to explaining the differing results of Reference 6-5 vs. Reference 6-6. The first study (Ref. 6-5) used electronic means to simulate the boom while the second study (Ref. 6-6) used a shock tube which is one difference. There are a number of other possibilities that might be offered to explain the more than 20 dB difference in threshold of acceptability, but it could also be related to the differences between instructions or the subject's task as they saw it. So that a comparison between the two sets of instructions can be made, those that are pertinent to the acceptability judgments for Reference 6-6 are provided.

INSTRUCTIONS FOR LABORATORY STUDY (Ref. 6-6)

"After recording your annoyance response, I want you to place a check under "yes" or "no" in the right-hand column under "Acceptable" to indicate whether or

not you believe the boom you have just hear would be acceptable to you. By this I mean whether or not you feel that you could learn to live with it, if you heard it regularly in your home.

Please notice there are fifteen lines. There will be a total of 15 times in each of two sessions when you will record your responses. Each time you are asked to respond, you will enter 2 answers: a number to indicate your feelings of annoyance in relation to the standard, and a check under "yes" or "no" to show whether or not you could learn to live with this annoyance. Are there any questions?"

One of the main differences between the two sets of instructions is that the first set (Ref. 6-5) asks the subjects to make a prediction on the basis of 25 signals spread out over their waking hours while the second set (Ref. 6-6) instructs the subjects to estimate number on the basis of, "if you heard it regularly in your home". Regularly could mean to the subject at the rate that they heard them during the experiment or at about 22 signals per hour; also, since sleep periods were not excluded, it is possible that some subjects thought that they were making predictions for the sleeping hours as well as for their waking time. A second point is that the first set of instructions only mentions "accept this sound" while the second set (Ref. 6-6) uses annoyance, implying that the sounds should be annoying and thusly unacceptable.

In summary, the almost total uniqueness of the real life living approach using simulated sonic booms leads to unusual difficulties when attempting to compare the results to those from previous studies. In fact, there have been very few studies aimed at establishing a threshold of boom acceptability as a means of establishing design and certification criteria for an advanced supersonic commercial aircraft.

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7. SOME QUALITATIVE OBSERVATIONS

When completing a human response study there are valuable and interesting data over and above that obtained by quantifying results to the formal items of the Daily and Weekly Noise Schedules. Some of these qualitative data were obtained on a spontaneous basis during the regularly scheduled interviews but most of it was obtained from interviews of three husband-and-wife pairs during the week just following their completion of participation in the experiment. Two members of the research group visited them in the evening and asked them to talk about the experience. Their comments are presented without attempting to order, classify, or interpret them.

Two pregnant women took part in the study and both independently reported that their fetuses first moved or responded to the booms but within a day or two adapted and did not respond. At least three persons spontaneously commented that the booms seemed louder when they were unoccupied or just listening as opposed to when they were actively engrossed in some activity such as reading or sewing.

The next set of comments are from the meeting with the couple designated as Family 5. The wife began by saying that they didn't bother them one iota and felt that they were not good subjects since they (the booms) didn't annoy. The first boom startled the wife but none did after that. Husband felt that levels during a particular week were not consistent (levels varied). He told a story of a law officer stopping at the front door to inquire about something and one of the booms came on (high level boom). The officer reached for his gun thinking it was a shot having been fired. The couple told of having friends over so they could hear the sounds. Their friends reactions were:

- Someone had fallen out of bed.
- Something had hit the roof.
- All friends had attitude of "so what".

The high level booms rattled bottles and jars in their bathroom. On one occasion during the week that they were exposed to the low level boom, the timer did not turn the system off at 10:00 PM. Their children and their children's friends were not awakened by the low level booms. Husband mentioned that helicopters coming over their house are more annoying than our booms. Husband thought that they

would have been more annoying if they would have been exposed for a longer duration.

The second family is designated as Family 4. The wife began by telling us how the high level booms made her mother who was visiting jump. The husband reported that he wouldn't take part in the experiment again. They told of having visitors from California whom they asked what kinds of noises they were experiencing. Their visitors told them, "Why, those are sonic booms. We've heard them from airplanes back home." They both thought that the experiment was tiring for the wife. They said they were really bothered by the high level booms. Husband thought that a single boom would be more annoying and shifting in volume (maybe fullness?) would also be more annoying. He kept calling the signals sharp booms. Husband mentioned that he noticed other noises in the environment to a greater extent since taking part in the experiment and also noticed increase in irritability due to noises in general. He thought that he could live with the low level booms at one time but since the experiment is over he doesn't think so. Wife believed that she could live with quietest sounds.

Family 1 was the last couple interviewed. The husband started the conversation by pointing out that the equipment ran well. They said that they were bothered more by the sounds if their kids were in school. On weekends when their kids slept in, it took the loudest (high level) sound to wake kids up in the morning. They told of having visitors one evening and forgot to warn them about the sounds and one came on. The visitor said, "What's that? What hit the house?" Husband thought they would have been less annoyed if regularly scheduled. During the high level boom period, could hear many feet away from house at their mailbox. In response to a question, the husband said the signals sounded like a pile driver. He said the noise didn't bother him but the high level ones did vibrate the house. Wife said if talking on the telephone they could make her lose her train of thought and the high level ones bother her with everything she did. They said that they would do it again just so they had only one week of the bad (meaning high level booms).

8. CONCLUSIONS

There were two objectives for this program. The first involved establishing a threshold of acceptability for design/certification of advanced commercial supersonic aircraft while the second objective was to demonstrate the feasibility of obtaining unbiased results using a community noise simulation system while families are participating in their usual day-to-day activities.

- In respect to the first objective of establishing a design/certification sonic boom threshold of acceptability for advanced supersonic transports, it is concluded that 87 dB using Stevens' Mark VI should be seriously considered as a design/certification criteria for indoor living with not more than fifteen daily exposures. If a conservative estimate for house noise attenuation of 18 dB is utilized, this means that outdoor booms would have an upper limit of 105 dB (Ref. 8-1 shows 24 dBA for house attenuation while results from Ref. 8-2 give some values above 26 dBA).

- In respect to the second objective of demonstrating that a community noise system simulation approach is feasible and has high utility, it is concluded that such an approach is indeed highly valuable and useful as a means of establishing community noise criteria. It can be used to establish standards involving traffic noise, noise from airports, construction noise, and effects of industrial noise on surrounding communities.

In respect to the design/certification criteria of 105 dB using Stevens' Mark VI for outdoor booms, the fact that the result is based on the experience of twenty-four adult persons only suggests that research with a larger number of persons is highly desirable. However, these persons did show test results indicating that they were highly sensitive to noise so the results could be conservative. Also, the house attenuation factor of 18 dBA should be investigated carefully since it is based on too little data (two situations only, Ref. 8-1 and 8-2).

In addition there is the possibility that the simulation approach was not representative. This possibility could be checked in a laboratory study using an electronic simulation approach in conjunction with a shock tube. If subjects responded in a similar manner to the simulated booms from the two approaches, it could be concluded that the electronic system was satisfactory. Since the system utilized did provoke startle and house shaking results similar to those from actual sonic booms, the element of realism was certainly present using the electronic method.

Other minor changes for future studies are to reduce the number of interviews with each family and to use a wave-form generator in each simulator instead of a tape recording. Our participants grew tired of being interviewed on a daily basis which could negatively affect the results. If each community noise simulation system contained its own wave-form generator, we would have had greater control over the signals presented (could vary them to a greater extent) and would have reduced tape wear problems. However, the six systems were designed and constructed to accommodate two studies, this sonic boom study and an aircraft flyover program, so the tape approach was essential for the flyover program.

A final caution in applying the results involves the fact that our families were related to by our staff in a very neutral manner. The sounds were not called sonic booms and every means were maintained to not communicate our expectations (if any) to the families. Of course, this is not the real life situation where pressure groups, both for and against, are influencing public opinion. Consequently, the accuracy of the recommended acceptability threshold would also be a function of the "climate of the times". Our aim was to provide an unbiased design/certification threshold.

8. REFERENCES

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APPENDIX 1

Frequency Spectrum of N Waves with Finite Rise Time

P. B. ONCLEY AND D. G. DUNN

Commercial Airplane Division, The Boeing Company, Seattle, Washington 98124

Several investigators have derived expressions for the pressure spectrum of the sonic-boom N wave. Where the rise time is zero, Howes has shown that the pressure spectrum is a published spherical Bessel function. The present analysis shows that the spectrum with a finite rise time, not exceeding one-tenth of the duration, can be closely approximated by multiplying two spherical Bessel functions, or, equivalently, by adding their logarithmic curves.

WITH RECENT INTEREST IN THE SUPERSONIC TRANSPORT AND THE associated sonic-boom problem, several investigators—notably Zepler and Harel,[1] Young,[2,3] Howes,[4] and Austin[5]—have derived

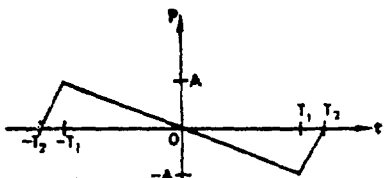

FIG. 1. Symmetrical N wave with a finite rise time.

expressions for the spectrum distribution of N waves. Young[2] has published curves for the case of zero rise time and has also shown[3] that the loci of maxima for an N wave with finite rise time fall along a negative 12-dB/oct slope above an inflection point determined by the rise time. Howes has derived a simpler expression for the zero-rise-time case and has corrected an evident typographical error in Young's equation. Zepler and Harel have considered only the initial rise function, ignoring the remainder of the N wave. Austin's analysis appears to be incorrect, since it leads to a vanishing function in the limiting case as the rise time goes to zero.

We have followed a similar approach to that of Howes, using the nomenclature given in Fig. 1. The pressure function is given by

$$P(t)=\begin{cases}-At/T_1, & |t|\leq T_1,\\ -A(T_2-t)/(T_2-T_1), & T_1\leq|t|\leq T_2,\\ 0, & \text{OTHERWISE.}\end{cases} \quad (1)$$

Since the expression is symmetrical and an odd function, the Fourier transform can be written

$$P(\omega)=\int_{-\infty}^{\infty}P(t)[\cos(\omega t)-i\sin(\omega t)]dt=-i2\int_0^{\infty}P(t)\sin(\omega t)dt$$

$$=2iA\left[\int_0^{T_1}\left(\frac{t}{T_1}\right)\sin(\omega t)dt-\int_{T_1}^{T_2}(t-T_2)\frac{\sin(\omega t)dt}{(T_2-T_1)}\right] \quad (2)$$

$$=2iAT_2\left\{\left[\left(\frac{T_2}{T_1}\right)\sin\left(\frac{T_1x}{T_2}\right)-\sin x\right]\Big/\left[x^2\left(1-\frac{T_1}{T_2}\right)\right]\right\},$$

where $x=\omega T_2=2\pi fT_2$.

Since in most cases of interest the rise time is a small fraction of the total duration, this can be approximated by

$$P(\omega)\simeq iAD\{\sin(\pi fD)/(\pi fD)^2-[\cos(\pi fD)/(\pi fD)][\sin(\pi fR)/(\pi fR)]\}, \quad (3)$$

where $D=T_1+T_2\simeq 2T_2$ and $R=T_1-T_2$.

For the case of zero rise time, $\sin(\pi fR)/(\pi fR)$ goes to unity, and the expression reduces to that of Howes:

$$P(\omega)=iADj_1(\pi fD), \quad (4)$$

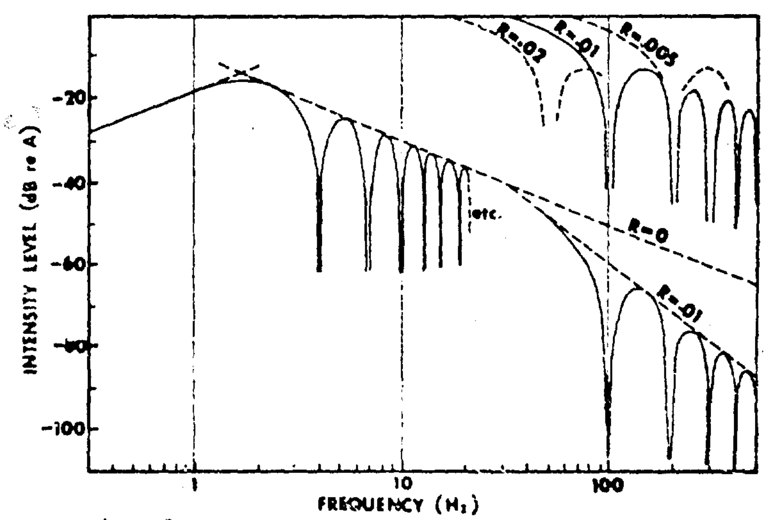

FIG. 2. Energy spectral density $W(\omega)$ for N wave with finite rise time.

where $j_1(v)$ is the spherical Bessel function of first kind and order. Further inspection shows that $\sin(\pi fR)/(\pi fR)$, which is identical with $j_0(\pi fR)$, does not depart significantly from unity (assuming that $R<0.1D$), except at frequencies high enough that the first term in Eq. 3 becomes negligible—i.e., when $j_1(\pi fD)\simeq j_{-1}(\pi fD) = \cos(\pi fD)/(\pi fD)$. That this is true at the frequencies of practical concern is apparent in comparing the published curves[6] for $j_1(v)$ and $j_{-1}(v)$, which are almost identical above the third or fourth maximum.

Accordingly, we can replace Eq. 3 by

$$P(\omega)\simeq iADj_1(\pi fD)\cdot j_0(\pi fR) \tag{5}$$

for cases of practical interest. In Fig. 2, based on Young's plot of the energy spectral density for zero rise time, we have added a logarithmic curve, $20\log_{10}|j_0(\pi fR)|$, for rise times of 5, 10, and 20 msec. To minimize complexity, we have omitted peaks beyond the second maximum. Since both curves are logarithmic, they may be added to give the function $W(\omega)=20\log_{10}|iDj_1(\pi fD)\cdot j_0(\pi fR)|$. The representative solution for $R=10$ msec is shown. D is taken as 350 msec. In the range above 50 Hz, the maxima of the j_1 function come so closely together as to approximate a continuous spectrum, but the cyclic character of the j_0 component then becomes significant.

This is in agreement with Young's analysis (Ref. 3) as regards the −12-dB/oct slope of the higher peaks, but the implication is quite different as far as subjective loudness is concerned. The peaks of $j_0(\pi fR)$ are widely spaced in the audible region, so the total energy contributing to loudness is very much less than that of a continuous spectrum with slopes at −6 and −12 dB/oct. With the −12-dB/oct slope, the higher maxima are very rapidly reduced to levels that contribute very little loudness—as a result of the limited range of sensitivity of the ear to low-frequency sounds—and we can virtually consider the finite rise time as equivalent to a fairly good low-pass filter with a cutoff at a frequency represented by $1/R$, with a very minor contribution from the higher lobes.

Zepler and Harel's analysis could be given in the form

$$P(\omega)=[j_0(\pi fR)]/(2\pi f) \tag{6}$$

for the initial rise only. This can be derived from our Eq. 5 by letting the duration D approach infinity. Thus, the agreement that they obtained with experimental data is appropriate to our expression also, since they are equivalent above the minimum range of audibility.

The expression without approximations, Eq. 2 above, has been evaluated on a large digital computer and is essentially the same as the plot given in Fig. 2.

In view of the great difference in loudness that grows out of variation in rise time and the wide range of rise time reported in actual sonic-boom tests, it would seem profitable to study in more detail the causes of these variations. Since higher altitudes often lead to longer rise time, there is some question of the validity of the publicized sonic-boom tests where the predicted overpressure of supersonic transports has been simulated by smaller aircraft at lower altitudes. It should be recognized that peak overpressure alone is not an adequate criterion for defining the annoyance arising from sonic booms.

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APPENDIX 2

DISCRIMINATIONS AMONG SIMULATED SONIC BOOMS

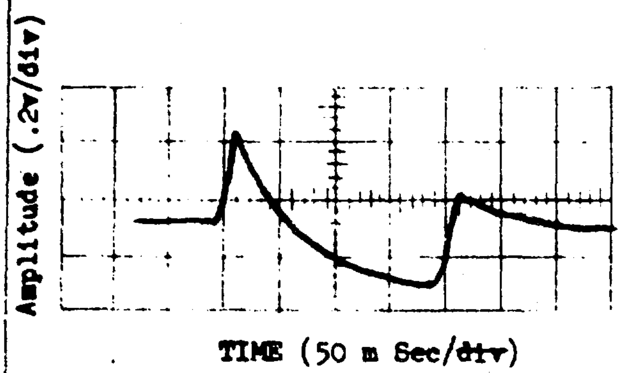
Presented at Acoustical Society of America Meeting, November 14-17, 1967, Miami Beach, Florida.

This is a report on the first study of a series where the aim of the series of studies is to develop a broad understanding of man's response to impulsive noise, but with emphasis on man and sonic booms. One of the major difficulties in carrying out experiments in this area involves realistic acoustic simulation of both outdoor and indoor booms plus simulation which produces the whole body sensation of being "hit" by the boom. We are looking at approaches which may lead to more realistic or total simulations but for the present are limiting the experiments to acoustic simulations of outdoor booms.

METHOD

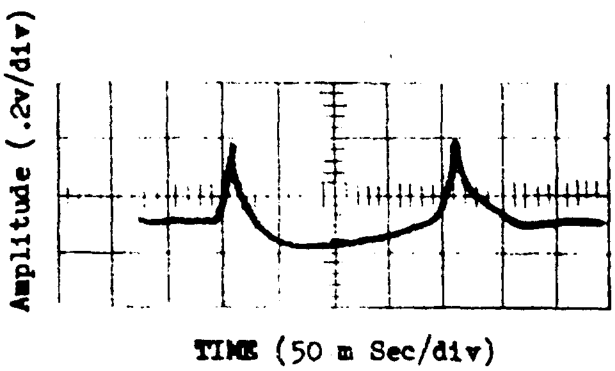
A waveform generator was constructed which provided for the introduction of sounds represented by four different waveforms into a box 21 inches square, 25 inches in height, and with an 18 inch speaker mounted in the top of the box. The four waveforms were an N-wave, a differentiated N-wave, one-half square-wave, and a differentiated one-half square-wave. Examples of these four wave forms are given in Figure 1. The aim was to approach zero as a limit for the rise time. However, rise times of 3 msecs were the smallest we could achieve so all the sounds were presented at this minimum achievable rise time. The period for all of the waveform presentations was held constant at 300 msec. Two amplitudes were used; one group of seven subjects were exposed to all of the waveforms at .94 psf while a second group composed of nine persons made judgement of the waveforms at 1.87 psf.

EXAMPLES OF WAVE FORMS INVESTIGATED



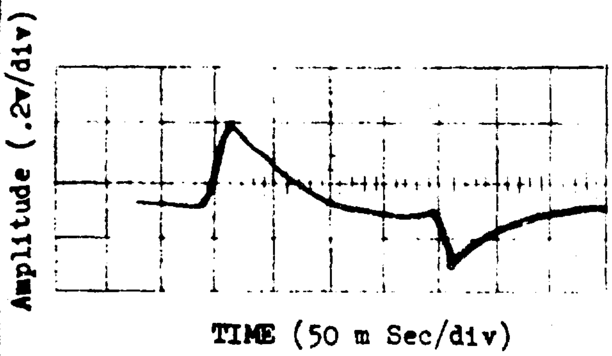
N Wave With Subject

(a)



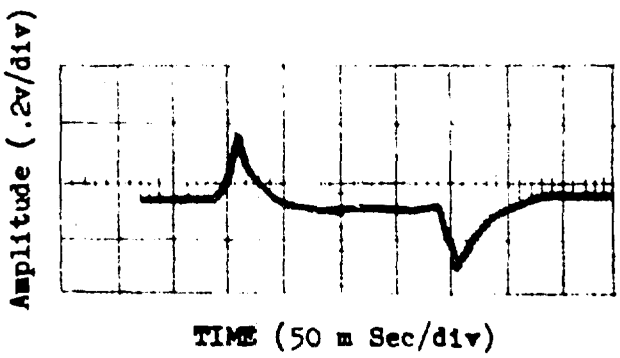
dN Wave With Subject

(b)



S Wave With Subject

(c)



dS Wave With Subject

(d)

FIGURE 1

Since the aim of the study was to determine if the auditory effect of the four different waveforms was similar, each waveform was paired with all other waveforms (leading to six comparisons). The pairings were made by making a single presentation of one waveform with three presentations of the waveform to which it was being compared. In turn, the waveform that was used as a comparison was presented singly with three sounds represented by the other member of the pairing. For example, an N-wave was presented with three differentiated N-Waves. and a single or "only" differentiated N-wave was presented with three N-waves. Thusly, each subject heard sounds in groups of four and made judgements for twelve groups of sounds. (Each group was presented with 5 seconds between each sound.) Orders of presentation for the twelve groups of stimuli were randomly assigned as was the position in which the single stimulus was presented; i.e., first, second, third, or fourth position. With his head sealed in the box, the subject's task was to listen to the twelve groups of four sounds and identify the one sound in each group of four which was different from the other three sounds.

RESULTS

Since there was no significant difference ($P > .05$) between the two groups of subjects (group judging impulse sounds at .94 psf vs. group judging sounds at 1.87 psf) in terms of correctly identifying the single stimulus of a group of four, results for both groups are

presented together. Figure 2 gives the percentage of times that the "only" waveform was correctly identified for each of the six pairings. On a chance basis, it is expected that the single stimulus would be correctly identified twenty-five per cent of the time. The horizontal line of Figure 2 labeled "% Correct Expected on a Chance Basis" shows the point for correctly identifying the single stimulus twenty-five percent of the time. The horizontal line labeled "% Required to Reach .01 Level of Confidence" is based on an expansion of the binomial distribution function ($(p+q)^N$ where $p = 1/4$, $q = 3/4$, $N = 32$). Any value above this point would occur on a chance basis less than 1% of the time so the conclusion is accepted that correct identification of the single stimulus more than approximately 41% of the time means that subjects can, on the average, distinguish between the two sounds of a pairing. Examination of Figure 2 leads to the conclusion that subjects cannot discriminate between N-waves and differentiated N-waves or between one-half square-waves and differentiated one-half square-waves. However, for the remaining four pairings, where comparisons are made between the various N-waves and one-half square waves, the subjects could, on the average, discriminate between sounds represented by the waveforms.

CONCLUSIONS AND DISCUSSION

The finding that subjects could not discriminate between an N-wave and a differentiated N-wave has been most valuable in creating stimuli for more detailed studies of the effects of the physical parameters

PERCENT TIMES "ONLY" STIMULUS CORRECTLY IDENTIFIED WHEN PRESENTED WITH THREE OTHER STIMULI OF PAIR

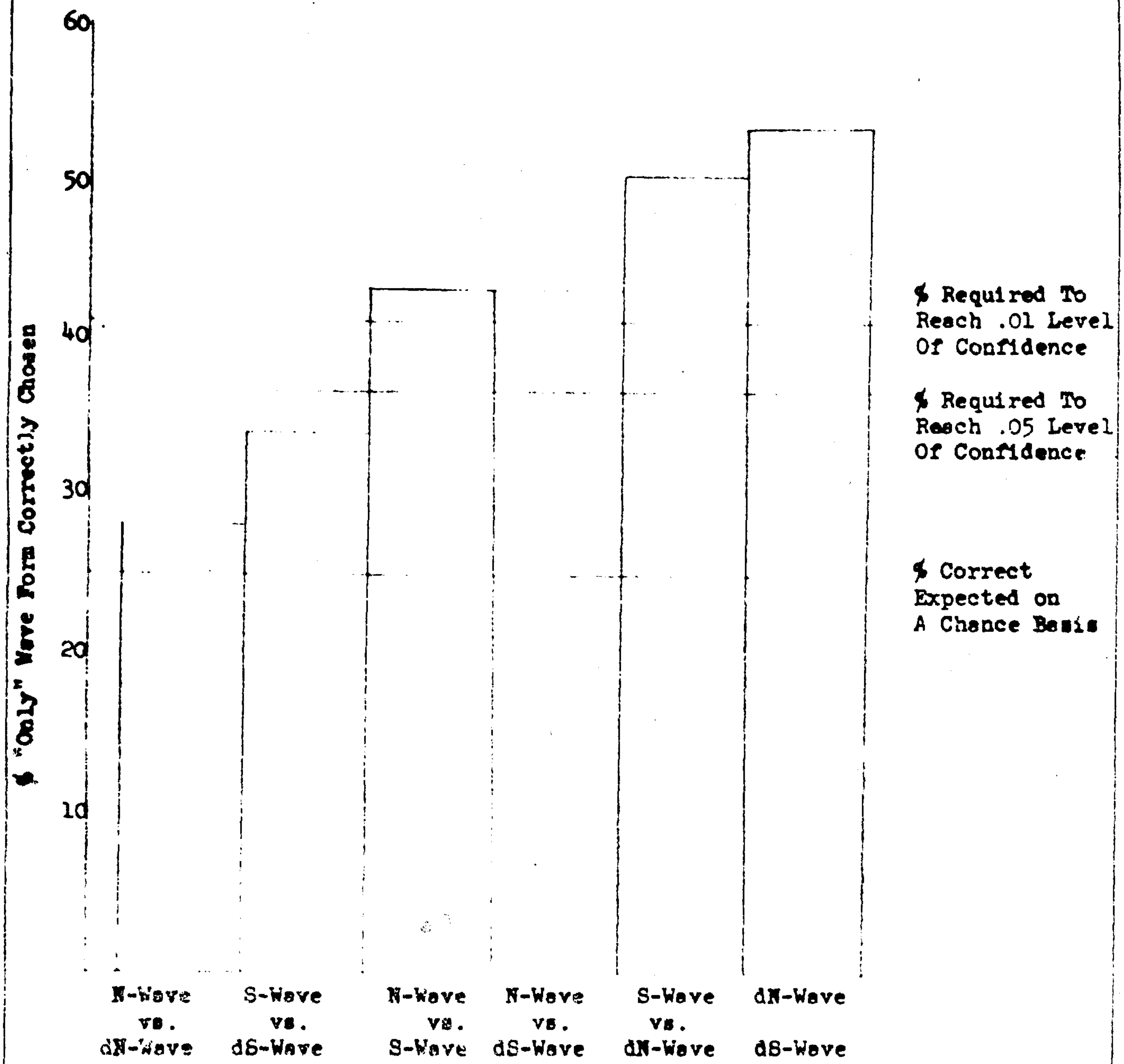


FIGURE 2

of impulse noise on man's acoustic response. Because of applied implications there is particular interest in varying rise time. Since rise time is, for the most part, determined by the high frequency components, we have been attempting to control rise time by filtering out or adding these components. With the N-wave, we have experienced little success in controlling rise time by using a filter in that we obtain unequal rise times for the two pulses. Since the use of one filter does not give equal rise times for the two pulses, two filters with different characteristics are required for each pulse. Since this approach is quite complicated electrically, it is to be avoided. Another telling reason for attempting to find a waveform which produces the same acoustical effect as the N-wave is the difficulty in reproducing the slow decay rate of the N-wave. Air leakage causes a loss of low frequency components and a consequent increase in the decay rate (the wave becomes differentiated). This problem becomes more pronounced as the size of the chamber increases. However, with the differentiated N-wave, it is relatively easy to control rise time with one filter and keep the amplitudes and rise times of the two pulses equal, and since differentiated N-waves have the same acoustical effect as N-waves, reproduction of the slow decay rate of the N-wave is not required. Consequently, differentiated N-wave forms are being used for present studies with the assumption that the effect is similar to that achieved by sounds represented by N-waves.

Also, support for proceeding on this basis is found in the results of some experiments completed by Zepler and Harel (4). Using specially constructed earphones and with their subjects adjusting a 400 c/s tone to match the loudness of N-waves, their experiments showed that the loudness of the N-wave is determined by the two rising parts. Further support is found in our data in that subjects could not discriminate between one-half square-waves and differentiated one-half square-waves while discriminations were made in all four pairings when pulses between members of a pair pitted compression against rarefaction.

An explanation of this discrimination (compression vs. rarefaction) involving the auditory mechanism is suggested by findings reported by Deatherage and Henderson (2) in conjunction with some earlier work by Peake and Kiang (3). Deatherage and Henderson found that the auditory threshold is lower when a signal is added during the condensation phase of the stimulus (when the basilar membrane is moving downward) than when added in the rarefaction phase (basilar membrane moving upward). Since eighth nerve single fiber responses occur only during the rarefaction half-wave of a stimulus (1) and the eighth nerve action potential is greater for a condensation click than for a rarefaction click (3), Deatherage and Henderson conclude that movement resulting from compression induces a state of hypersensitivity--"priming" the neural elements to be fired on the following rarefaction. Hence, we can hypothesize that discriminations between the N-wave and one-half square-wave were made on the basis of the second pulse of the N-wave

(compression half-wave first) being experienced as louder than the second pulse of the square-wave (rarefaction half-wave first). Consequently, results similar to ours should be achieved if discriminations were to be made on the basis of loudness instead of "which of the waveforms are different?"

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